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PREFACE.

THE present volume contains nine out of the ten papers presented at the Annual Meeting held in London on May 1, 2 and 3, 1935, together with the discussions and correspondence on them. The other paper was the " Third Report of the Corrosion Committee " ; this Report was printed as a separate volume marked " Special Report No. 8." The discussion on this is published in the present volume of the Journal. At the end of Section I. will be found an account of the speeches made at the Annual Dinner.

Section II. contains the usual notes on the progress of the home and foreign iron and steel industries as reported in the proceedings of the scientific and technical societies and in the technical press, together with notices of new books presented to the Institute and a bibliography of the principal works dealing with the metallurgy of iron and steel and allied subjects which have appeared during the half year.

In front of the title page is inserted a list of the British Standardised Steel Samples, issued jointly by the Iron and Steel Institute and the National Physical Laboratory, showing where and on what terms the samples are available. Proposal forms for Membership and Associateship of the Institute will also be found in the same place.

28 VICTORIA STREET, LONDON, S.W.1
September, 1935.

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Abbreviations Used in the Text.

Å.	Ångström unit(s).
A.-C.	air-cooled.
a.c.	alternating current(s).
A.-H.	air-hardened.
amp.	ampère(s).
amp.-hr.	ampère-hour(s).
atm.	atmosphere(s) (pressure).
Bé.	Baumé (scale).
B.H.P.	brake horse-power.
B.O.T.	Board of Trade.
B.th.u.	British thermal unit(s).
B.T.U.	Board of Trade unit(s).
B.W.G.	Birmingham wire-gauge.
C.	centigrade (scale).
cal.	calory ; calories.
c.c.	cubic centimetre(s).
c.d.	current density.
cg.	centigramme(s).
c.g.s.	centimetre - gramme - second unit(s).
cm.	centimetre(s).
coeff.	coefficient.
const.	constant(s).
c.p.	candle-power.
cu.	cubic.
cwt.	hundredweight(s).
d.c.	direct current(s).
dg.	decigramme(s).
diam.	diameter(s).
dm.	decimetre(s).
e.m.f.	electromotive force(s).
F.	Fahrenheit (scale).
ft.	foot ; feet.
ft.-lb.	foot-pound(s).
gal.	gallon(s).
grm.	gramme(s).
H.-F.	high-frequency.
H-ion	hydrogen-ion.
H.P.	horse-power.
H.P.-hr.	horse-power-hour(s).
hr.	hour(s).
in.	inch ; inches.
in.-lb.	inch-pound(s).
K.	absolute temperature (scale).
kg.	kilogramme(s).
kg.-m.	kilogramme-metre(s).
km.	kilometre(s).
kva.	kilovolt-ampère(s).
kw.	kilowatt(s).
kw.-hr.	kilowatt-hour(s).
lb.	pound(s).
L.-F.	low-frequency.
m.	metre(s).
m.-amp.	milliampère(s).
m.-volt	millivolt(s).
max.	maximum.
mg.	milligramme(s).
min.	minimum ; minute(s).
ml.	millilitre(s).
mm.	millimetre(s).
m.m.f.	magnetomotive force(s).
N.	normal (solution).
N.T.P.	normal temperature and pressure.
O.-H.	open-hearth ; oil-hardened.
O.-Q.	oil-quenched.
oz.	ounce(s).
p.d.	potential difference.
R.	Réaumur (scale).
r.p.m.	revolutions per minute.
sec.	second(s).
sp. gr.	specific gravity.
sq.	square.
T.	tempered.
temp.	temperature.
v.	volt(s).
va.	volt-ampère(s).
w.-hr.	watt-hour(s).
W.-Q.	water-quenched.
yd.	yard(s).
°	degree(s).

SECTION I.

MINUTES OF PROCEEDINGS

AND PAPERS OF

THE IRON AND STEEL INSTITUTE.

ANNUAL MEETING

1935

Editorial assistance has been given by A. E. CHATTIN, B.Sc. (Hons. Met.), A.I.C., Assistant Secretary, in the preparation of this Section.

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MINUTES OF PROCEEDINGS

AND

PAPERS AND DISCUSSIONS

AT THE

ANNUAL MEETING, 1935.

THE SIXTY-SIXTH ANNUAL MEETING OF THE IRON AND STEEL INSTITUTE was held at the Institution of Civil Engineers, Great George Street, Westminster, on Wednesday, Thursday and Friday, May 1, 2 and 3, 1935, the two latter days being devoted to a Symposium on the Welding of Iron and Steel organised by the Iron and Steel Institute in co-operation with other Technical Societies.

The first day was given to formal business, and the discussion of papers presented to the Institute. Mr. W. R. LYSAGHT, C.B.E., the retiring President, was in the Chair, and was followed later by Sir HAROLD CARPENTER, Ph.D., F.R.S., the incoming President.

The Minutes of the last General Meeting were taken as read and confirmed.

BALLOT FOR ELECTION OF NEW MEMBERS.

Mr. A. F. WEBBER (London) and Mr. T. STEVENSON (London) were appointed scrutineers of the ballot for the election of new Members and Associates, and they subsequently announced that the following fifty-seven candidates for membership and twelve candidates for associateship had been duly elected:

MEMBERS.

ASADA, CHOHEI	Kobe, Japan.
AUSTIN, *Dr.* CHARLES R. . . .	Pennsylvania, U.S.A.
BAVISTER, HAROLD SIDNEY . .	Luton.
BOËL, LUCIEN	Brussels, Belgium.
BOOL, EDMUND DOUGLAS . .	Sheffield.
BURTON, HERBERT HENRY . .	Sheffield.
CALOW, THOMAS ARTHUR . .	Sheffield.
COUSE, ALFRED	Sheffield.
CROW, THOMAS BENEDICT, Ph.D., A.I.C.	Birmingham.

DAVISON, GEORGE HARLEY . .	Stocksbridge.
DAVY, CHRISTOPHER HUMPHREY .	London.
DELBART, GEORGES ROBERT, *Dr. ès Sc.*	Denain (Nord), France.
DENNIS, CLAUDE C. . . .	New York, U.S.A.
DRINNAN, ROBERT GIFFEN, jun., D.Sc.	Lorain, Ohio, U.S.A.
ECK, HENDRIK JOHANNES VAN, M.Sc., D.Eng.	Pretoria, S. Africa.
GANDHI, INDOO NAGARDAS . .	Jamshedpur, India.
GEISLER, WILLIAM A. . . .	Frankfurt-am-Main, Germany.
GOSSELIN, ANDRÉ	Paris, France.
GRANT, LEONARD	Newcastle, N.S.W., Australia.
GREGORY, ERNEST WILLIAM, A.M.I.Mech.E.	Sheffield.
GRIFFITHS, LESLIE JAMES. . .	Newcastle, N.S.W., Australia.
GRIFFITHS, THOMAS ADDIE . .	Newcastle, N.S.W., Australia.
HARRIS, HERBERT, Ph.D., B.Sc., D.I.C., A.R.C.S.	Renfrew.
HENRICOT, JACQUES . . .	Court St. Etienne, Belgium.
HITCHINS, *Colonel* CHARLES FAUNCE, D.S.O.	London.
JAMES, EDWARD ALFRED . . .	West Hartlepool.
JONES, NORMAN E. T. . . .	Newcastle, N.S.W., Australia.
KNIGHT, RONALD LESLIE . . .	Wollongong, N.S.W., Australia.
KORB, LEIGHTON FREDERICK . .	Dagenham.
LEE-BIRD, WILLIAM JOHN . .	Coventry.
LEHMANN, FRITZ	Köln-Mülheim, Germany.
LOSKIEWICZ, *Professor Dr. Ing.*, WLADYSLAW	Cracovie, Poland.
LOWE, ROBERT	Bexley Heath, Kent.
MALKIEWICZ, TADEUSZ . . .	Katowice, Poland.
NEAVE, DIGBY PERCY CORNWALL, N.A.	London.
NOYES, EDWARD MANNINGFORD, B.A.	Wirral, Cheshire.
PARK, CYRIL JOHN	Wigan.
PARRY, TREVOR	Nottingham.
REICHWALD, OTTO F. . . .	London.
ROBINSON, ERIC A., M.C., A.M.I.Mech.E.	London.
SANKEY, GEORGE RONALD, M.A. (Cantab.), A.M.I.E.E. . . .	Wolverhampton.
SANKEY, *Colonel* HAROLD BANTOCK .	Bilston.
SELIGMAN, RICHARD, A.C.G.I., Ph.met.D., F.I.M. . . .	London.
SHAUER, JULIUS	Moscow, U.S.S.R.

SNEDDEN, WILLIAM PATERSON .	Birmingham.
SOUTTER, JOHN WILLIAM PAUL. .	Manchester.
STAHL, FRANK	Johannesburg, S. Africa.
TAVERNER, IAN DIGBY . . .	London.
TAYLOR, ARTHUR	Manchester.
TODHUNTER, WILLIAM JAMES . .	Newcastle, N.S.W., Australia.
WALKER, WILLIAM SHELLEY, M.Sc. .	Crewe.
WARD, GILBERT O. . . .	Cleveland, Ohio, U.S.A.
WHINCUP, NORMAN	Warrington.
WHITAKER, ALFRED, M.A. (Cantab.), A.M.I.E.E.	Hayes, Middlesex.
WHITNEY, L. C.	Glassport, Pa., U.S.A.
YOSHIOKA, *Vice-Admiral* YAWUSADA .	Kobe, Japan.
YOUNG, JAMES RAYMOND . .	Newcastle, N.S.W., Australia.

ASSOCIATES.

BANFIELD, THOMAS ARTHUR Ph.D. .	Birmingham.
DAVIES, WILLIAM HERBERT . .	Swansea.
HOLLAND, EDGAR	Motherwell.
LANG, JOHN, A.M.I.Mech.E. . .	Middlesbrough.
MACQUARIE, CHARLES . . .	Glasgow.
MOOREY, ERNEST HENRY ST. CLAIR .	Luton.
POOLE, FRANK H.	Bolton.
PORTEOUS, JOSEPH, jun. . . .	Glasgow.
PUTNAM, SYDNEY LAWRENCE . .	London.
SANITER, FRANK HENRY . . .	Rotherham.
SMITH, WILLIAM ANDERSON . .	Glasgow.
WHITFIELD, JOHN FRANCIS . .	Middlesbrough.

PRESENTATION OF ANNUAL REPORT AND STATEMENT OF ACCOUNTS FOR 1934.

Mr. W. R. LYSAGHT, C.B.E., the retiring President, presented the Annual Report and Statement of Accounts for 1934. The members would all regret, he said, that Mr. James Henderson, the Hon. Treasurer, was unable to be present owing to illness, but he was glad to say that the illness was not a serious one.

Three Members of Council had died during the past year, namely, Mr. Walter G. Gray, who had been a member of the Council since 1927, Mr. Alexandre Pourcel, who had been a Vice-President since 1918, and Mr. E. H. Saniter, a member of the Council since 1921, and a Vice-President of the Institute. Mr. Pourcel was one of the oldest and most distinguished of French metallurgists, and his loss would be greatly regretted. Mr. Saniter was too well known to the members for it to be necessary to say anything about him, but by his death the Institute had lost one of its most distinguished members and a very old friend.

The motion for the adoption of the Report of Council and Statement of Accounts was carried unanimously.

REPORT OF COUNCIL.

THE Council of the Iron and Steel Institute have much pleasure in submitting for the approval of the members at this, the Sixty-Sixth Annual General Meeting, their Report on the proceedings and work of the Institute during the year 1934.

ROLL OF THE INSTITUTE.

During the past year ninety-one new members and nineteen associates were elected; seven associates were transferred to membership, and fifteen members were reinstated. Fifty members resigned their membership during the year. The total membership of the Institute on the register on December 31, 1934, was accordingly as follows:

Patron	1
Honorary Members	18
Life Members	74
Ordinary Members	1,770
Associates	55
	1,918

There was therefore a decrease during the year of eight in the number of ordinary members and an increase of ten in the number of associate members. The total number of members on the roll of the Institute is one less than a year ago.

It is with deep regret that the Council recall the death, on February 17, 1934, of His Majesty Albert I., King of the Belgians. King Albert had been an Honorary Member of the Institute since 1913, and it was largely due to the interest he showed that the visit to Belgium in that year proved particularly memorable.

The Council also regret to record the deaths of the following thirty members of the Institute which occurred during the year 1934:

Bagley, C. H. F. (Darlington)	November, 1934.
Ballard, H. (London)	?
Bentley, G. H. (London)	April 4.
Cheesewright, Col. W. F. (Dallington, Sussex)	October 12.
Clements, J. A. (Chesterfield)	October 13.
Corey, W. E. (New York)	May 11.

Crookston, A. W. (London)	February 21.
Crosbie, J. P. (Sheffield)	January 25.
Dickenson, J. H. S. (Sheffield)	November 16.
Flagg, S. G. (Philadelphia)	March 14.
Gray, W. G. (Member of Council) (Glasgow)	June 27.
Greensmith, T. (Sheffield)	June
Hall, B. J. (London)	April 28.
Hawdon, W. (Nunthorpe)	April 13.
Hayward, T. P. (Sheffield)	April 7.
Johansson, A. (Stockholm)	June 23.
MacGuckin, C. J. G. (London)	August 17.
Pourcel, A. (Hon. Vice-President) (Paris)	March 15.
Ridsdale, C. H. (Glaisdale, Yorks.)	December
Roe, J. P. (Douglassville, Pa.)	September 14.
Rosenhain, W. (London)	March 17.
Rowlandson, Major C. St. John (London)	August 3.
Sandberg, N. P. P. (London)	November 7.
Sankey, G. H. (Bilston)	December 19.
Saniter, E. H. (Vice-President) (Rotherham)	November 2.
Spencer, Sir T. Harris (Wednesbury)	April 30.
Veith, Hofrat Adalbert (Sulzburg)	March 19.
Wood, E. Escott (Stourbridge)	?
Wood, Walter (Philadelphia)	April 20.
Ybarra, J. A. de (Madrid)	January 24.

The deaths of the following five members took place prior to 1934, but were not reported to the Council until that year :

Bray, T. J. (Youngstown) (Life Member)	December, 11, 1933.
Edwards, D. A. (Swansea)	December 15, 1933.
Hoblyn, J. B. (Luton)	December 24, 1933.
Shaw, W. (Middlesbrough)	May 11, 1933.
Spranger, R. W. (Florence)	1933.

In reporting this list of names of members deceased, the Council specially desire to place on record an expression of their deep regret at the loss of their former colleagues, Mr. E. H. Saniter, Mr. A. Pourcel and Mr. W. G. Gray. Mr. Saniter was one of the older members of the Institute, having joined in 1892 ; he became a Member of Council in 1921, and was elected a Vice-President in 1927. Mr. Pourcel's association with the Institute was even longer ; he became a member in 1879 and was elected an Honorary Vice-President in 1918. Both Mr. Saniter and Mr. Pourcel were Bessemer Gold Medallists of the Institute. Mr. Gray became a member of the Institute in 1917, and was elected a Member of Council in 1927.

Finance.

The Statement of Accounts for the year 1934, which has been duly audited and certified by Messrs. W. B. Keen and Co., the Institute auditors, accompanies this Report, and is presented by Mr. James Henderson, the Hon. Treasurer, for the approval of the meeting.

The accounts are not readily comparable with those of previous years, owing to the changes in the method of presentation explained a year ago. The accounts for future years will be comparable with those now presented.

The income of the General Fund during 1934 was £7,714 15*s.* 11*d.*, and the expenditure £9,902 8*s.* 7*d.*, the result being an excess of expenditure over income of £2,187 12*s.* 8*d.* The receipts of the Special Appeal Fund during the year amounted to £2,032 7*s.* 0*d.*, and this figure has been taken into the accounts, leaving a net debit balance of £115 5*s.* 8*d.* to be carried to the Balance Sheet.

The expenditure for the year includes expenses of office decoration and equipment, the preparation of the Ten-Years' Index of the Journal and Carnegie Scholarship Memoirs, and salaries amounting to a total of £1,446, which will not recur in future years.

In the Balance Sheet the sum of £1,000, being part of the proceeds of the Special Appeal Fund during 1933 which was transferred to Suspense Account in the accounts for that year, is again included and is available for transfer to the Income and Expenditure Account when required, and there is also shown the transfer of a balance of £1,200 in respect of the Autumn Meeting from the Income and Expenditure Account to Capital and Reserve Account. For the sake of clarity, the Capital and Reserve Account is shown in greater detail.

During the year, the Council have reviewed the Institute's investments and made certain changes with the object of securing a wider distribution. The schedule of investments shows that the market price on December 31st, 1934, was £29,158 12*s.* 1*d.*, or £5,285 19*s.* 9*d.* in excess of the cost price of £23,872 12*s.* 4*d.*, at which they are included in the Balance Sheet.

As has been indicated above, the accounts for 1934 have again benefited by the inclusion of the proceeds of the Special Appeal Fund (amounting during the year to £2,032 7*s.* 0*d.*), the receipts of which were first included in the accounts of the previous year.

The Council wish to take this opportunity of recording their appreciation of the generous subscriptions received from individuals, companies and associations; without the income thus obtained, the activities of the Institute would of necessity have been drastically restricted.

Promises of subscriptions of a similar amount during 1935 have been received, and, as a result, the Council are confident that the activities of the Institute will be maintained. They consider, however, that it is incumbent upon them to point out that the future well-being of the Institute is dependent on an assured income of not less than that which has been received during the year under review; only if this is the case can the activities of the Institute be maintained and extended. They are confident that the fall in membership consequent on the depression of recent years has now, with the return of greater prosperity, ceased, and that with an increase in membership and the continued support of all sections of the Industry, the Institute will be able to maintain to its full extent the service which is given to members and all interested in the technical and metallurgical development of iron and steel.

The accounts of the Carnegie Research Fund, Bessemer Medal Fund and Williams Prize Fund, having been duly audited, are also presented.

Bessemer Gold Medal.

His Majesty King George V., Patron of the Institute, was graciously pleased to accept the Bessemer Gold Medal presented for the year 1934. A Deputation, consisting of Mr. W. R. Lysaght, C.B.E. (President), Sir Robert Hadfield, Bt., F.R.S. (Past-President), Sir Harold Carpenter, F.R.S. (Hon. Treasurer), and Mr. K. Headlam-Morley (Secretary), attended at Buckingham Palace on May 30 in order to present the Medal, and was most graciously received by His Majesty.

Election of Honorary Member.

His Majesty Leopold III., King of the Belgians, was graciously pleased to become an Hon. Member of the Institute on the occasion of the Autumn Meeting in Belgium. King Leopold is the third successive King of the Belgians to honour the Institute in this way.

Changes on the Council.

Election of New President.—Sir Harold Carpenter, F.R.S., was nominated by the Council to succeed Mr. W. R. Lysaght, C.B.E., as President.

Election of New Honorary Treasurer.—Mr. James Henderson was elected Honorary Treasurer to succeed Sir Harold Carpenter, F.R.S., who resigned this office as on October 1, 1934, on his nomination as President-Elect.

Other Changes.—Monsieur Léon Greiner (Seraing) and Monsieur Aloyse Meyer (Luxemburg) were elected Honorary Vice-Presidents of the Institute on the occasion of the Autumn Meeting in Belgium and Luxemburg. Lieut.-Col. Sir Maurice H. L. Bell, Bt., C.M.G., was nominated an Honorary Vice-President on November 8, 1934. In order to fill the vacancies caused by the nomination of Mr. James Henderson as Honorary Treasurer and by the death of Mr. E. H. Saniter, Dr. W. H. Hatfield and Sir William Larke, K.B.E., were nominated Vice-Presidents. The election of members of Council to fill the three vacancies was deferred.

In accordance with Bye-Law 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting as being due to retire at the Annual Meeting in 1935:

Vice-Presidents.—Mr. J. Henderson; The Hon. Roland D. Kitson, D.S.O.; Dr. C. H. Desch, F.R.S.

Members of Council.—Mr. J. E. James; Dr. W. H. Hatfield; Dr. A. McCance; Mr. P. B. Brown; Mr. A. O. Peech.

Mr. Henderson and Dr. Hatfield having been elected Honorary Treasurer and Vice-President, respectively, Mr. Arthur Dorman (Vice-President) and Mr. H. Leighton Davies become due to retire in their places.

No other members having been nominated up to one month previous to the Annual Meeting, the retiring members are presented for re-election.

Honours Conferred on Members.

The Council tender their most hearty congratulations to a number of members of the Institute on whom appointments of honour and distinction have recently been conferred.

Cav. di Gr. Croce G. E. Falck (Hon. Vice-President) and Mr. A. Bocciardo have been appointed Senators of the Kingdom of Italy. Professor A. M. Portevin has been nominated an Officer de la Légion d'Honneur. On Mr. L. Pendred and Mr. A. A. Bryant have been conferred the C.B.E. and O.B.E., respectively. Mr. John Craig, C.B.E. (Vice-President), is now Deputy Lieutenant for the County of Lanark. The late Mr. G. H. Sankey had accepted Office as High Sheriff of Staffordshire before his death, and Mr. Eugène Schneider (Past-President) has been elected a member of the Académie des Sciences Morales et Politiques, one of the five constituent Académies of the Institut de France. Mr. W. B. Pickering has been appointed Latvian Consul for the City of Sheffield. The Institution of Civil Engineers awarded Telford Premiums jointly to Mr. Vernon Harbord, and Mr. E. F. Law, and to Mr. L.

Ennis. The Thomas Turner Gold Medal had been awarded by the University of Birmingham to the late Dr. W. Rosenhain, F.R.S., before his decease. The Honorary Degree of Doctor of Laws has been conferred by the University of Sheffield on Sir Arthur Balfour, Bt., K.B.E. Mr. V. C. Faulkner has received the Oliver Stubbs Gold Medal of the Institute of British Foundrymen for his work on the metallurgy of cast iron. Dr. A. Sauveur is the first recipient of the Albert Sauveur Achievement Medal, recently established by the American Society for Metals, for his work in connection with the metallurgy of metals, and Dr. R. F. Mehl has been awarded the John Scott Medal by the Philadelphia Board of City Trust for " his discovery of a method of taking pictures through great thicknesses of steel for determining internal defects."

Mr. James Henderson (Hon. Treasurer) was elected President of the British Iron and Steel Federation for 1934, while Mr. A. J. Grant, Captain R. S. Hilton (Member of Council) and Mr. C. W. Kayser represented the Sheffield district, and Sir John Field Beale, K.B.E., Major J. M. Bevan, Sir William Firth and Colonel Sir Charles Wright, Bt., K.B.E., C.B. (Past-President), represented South Wales and Monmouthshire, on the Council of the Federation.

Sir Harold Carpenter, F.R.S. (President-Elect), was elected President of the Institution of Mining and Metallurgy for 1934–1935. Mr. B. F. Shepherd was President of the American Society for Metals; Mr. J. Fallon was President of the Birmingham Metallurgical Society, while Mr. H. E. Cookson (Hon. Member of Council) and Lieut.-Col. Wm. Routledge (Hon. Member of Council) were re-elected Presidents of the Staffordshire Iron and Steel Institute and the Cleveland Institution of Engineers, respectively, for a further period. Professor P. Chevenard was elected a Vice-President of the Société de l'Industrie Minérale; Dr. R. Genders, M.B.E., has become a Member of Council of the Institute of Metals, and Mr. H. B. Toy was re-elected President of the Tees Side Chamber of Commerce.

Annual Dinner.

His Royal Highness Prince George honoured the Institute by attending the Annual Dinner which was held at the Connaught Rooms on the evening of May 31.

Meetings.

The Annual Meeting of the Institute was held in the Lecture Theatre of the Institution of Civil Engineers on Thursday and Friday, May 31 and June 1, 1934, the Chair being taken by the

President, Mr. W. R. Lysaght, C.B.E. The Council desire to express their thanks to the Council of the Institution of Civil Engineers for permission again to hold the Annual Meeting on their premises.

The Autumn Meeting was held in Belgium and Luxemburg from September 10 to 14, as the outcome of a very cordial invitation received from the Industrialists of those two countries. Technical sessions for the discussion of papers were held on the mornings of September 10 and 11 in the Palais des Académies, Brussels, and the afternoons of those days were devoted to visits to various works. On the evening of September 10 the members were entertained at a Banquet at the kind invitation of the Groupement des Hauts Fourneaux et Aciéries Belges ; Monsieur Léon Greiner, President of the Reception Committee, occupied the Chair. After the Banquet the Mayor and Councillors entertained the members to a reception at the Hotel de Ville.

On September 12, the party visited works in the neighbourhood of Liége and travelled on to Luxemburg.

On the morning of September 13, a short General Meeting was held in Luxemburg ; Their Royal Highnesses the Grand Duchess Charlotte and the Prince Félix of Luxemburg honoured the Institute by their presence during the proceedings. The afternoon of that day and the following morning were devoted to visits to works, and on the afternoon of September 14, the party were entertained at a garden party by Her Royal Highness the Grand Duchess. On the evening of September 13, the Members were entertained to a banquet given by the Groupement des Industries Sidérurgiques Luxembourgeoises, at which Monsieur Aloyse Meyer, President of the Reception Committee, presided. This was followed by a Ball in the Hotel de l'A.R.B.E.D.

The Council desire to take this opportunity of expressing their sincere thanks to the Industrialists of Belgium and Luxemburg, and particularly to the Reception Committees in those countries and their respective Presidents, Monsieur Léon Greiner and Monsieur Aloyse Meyer, for the charming hospitality with which the members were received and for the great trouble which they took for the visitors' comfort and in making their visit interesting and enjoyable. They also offer their respectful thanks to Her Royal Highness the Grand Duchess Charlotte of Luxemburg and her Consort for the great honour which they showed to the Institute by their interest and participation in the meeting.

Co-operation with Local Technical Societies.

The Council are glad to be able to announce that during the year arrangements have been made with the Local Technical Societies mentioned below for co-operation in certain respects.

In accordance with these arrangements, the maximum age of Associate Membership of the Institute, the annual subscription for which is £1 1*s.* 0*d.*, has been extended to 30 in the case of Associate Members who are also Members of the Local Societies concerned. The papers presented at the General Meetings of the Institute are made available for presentation at Meetings of the Local Societies ; it is proposed, with the co-operation of the Societies, to extend the holding of Joint Meetings in local centres.

The Societies with which these arrangements have been made are the following :

Cleveland Institution of Engineers.
Lincolnshire Iron and Steel Institute.
Manchester Metallurgical Society.
Newport and District Metallurgical Society.
Sheffield Metallurgical Association.
Sheffield Society of Engineers and Metallurgists.
Staffordshire Iron and Steel Institute.
West of Scotland Iron and Steel Institute.

Following the Autumn Meeting three joint meetings were held with Local Societies in England. The first was organised jointly with the Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association, and was held in the Mappin Hall of Sheffield University on Monday, October 15. The second meeting was held jointly with the Cleveland Institution of Engineers in the Cleveland Technical Institute, Middlesbrough, on Monday, December 3, and the third, held jointly with the Lincolnshire Iron and Steel Institute, took place on Tuesday, December 11. Acknowledgments are due to the local organisers for their trouble and care in making the arrangements for the additional meetings, on the success of which they are to be congratulated.

Papers.

Thirty-one papers were contributed to the Proceedings of the Institute during the year. Of these, eighteen were presented at the Annual Meeting and thirteen at the Autumn Meeting. The Second Report of the Corrosion Committee, the First Report of the Blast-Furnace Practice Sub-Committee and a Report on Blast-Furnace Linings were published as separate volumes in the Special Report Series of the Institute. The following is a complete list :

"Second Report of the Corrosion Committee."—Being a Report by a Joint Committee of the Iron and Steel Institute and the National Federation of Iron and Steel Manufacturers to the Iron and Steel Industrial Research Council (Special Report No. 5).

"First Report of the Blast-Furnace Practice Sub-Committee."—Being a Report by a Sub-Committee of the Blast-Furnace Committee of the Iron and Steel Industrial Research Council (Special Report No. 6).

"Blast-Furnace Linings." Part I.—"An Examination of the Information Received in Reply to a Questionnaire Circulated to Iron Manufacturers," by A. T. GREEN. Part II.—"Some Properties of the Fireclay Products used for Blast-Furnace Linings," by A. T. GREEN, W. HUGILL, F. H. CLEWS and H. ELLERTON (Special Report No. 7).

ABRAM, H. H.—"The Influence of Vanadium on Carbon Steel and on Steels containing Nickel and Chromium."

ABRAM, H. H.—"The Value of Young's Modulus for Steel."

BONE, W. A., F.R.S., H. L. SAUNDERS and N. CALVERT.—"An Experimental Enquiry into the Interactions of Gases and Ore in the Blast-Furnace. Part III.—Proposed Methods for Comparative Testing of Iron Ores."

BONE, W. A., F.R.S., H. L. SAUNDERS and J. E. RUSHBROOKE.—"An Experimental Enquiry into the Interactions of Gases and Ore in the Blast-Furnace. Part IV.—Equilibria and Velocities in Ore Reduction."

DUSTIN, H.—"Belgian Research Committee on the Behaviour of Metals at Elevated Temperatures."

GILL, E. T., and R. GOODACRE.—"Some Aspects of the Fatigue Properties of Patented Steel Wire."

GRIFFITHS, R.—"The Blistering of Iron Oxide Scales and the Conditions for the Formation of a Non-Adherent Scale."

HÄGG, GUNNAR.—"The Decomposition of Martensite."

HATTORI, D.—"The Thermal Conductivity of Tool Steels."

HERBERT, E. G.—"Ageing Changes in Nitrided Steel."

HOARE, W. E.—"Tin-Iron Alloy in Tinplate with Notes on some Imperfections."

JENKINS, C. H. M., and W. J. WEST.—"Accelerated Cracking of Mild Steel (Boiler Plate) under Repeated Bending. Part II.—Further Tests."

JONES, W. D.—"The Influence of Diffusing Elements upon the Alpha-Gamma Inversion of Iron."

JONES, W. D., and W. E. HOARE.—"A Microscopic Examination of Iron-Tin Reaction Products."

MAURER, E., and W. BISCHOF.—"The Behaviour of Sulphur in Open-Hearth Furnace Gases."

MORRAL, F. R.—"The Constitution of Iron-Rich Fe–Al–C Alloys."

MORT, E. R.—"The Manufacture of Full-Finished Steel Sheets."

NORTHCOTT, L.—"A Study of Ingot Structures."

NORTHCOTT, L.—"Dendritic Segregation in Steel Ingots."

NORTHCOTT, L.—Periodic Structures in Metals and Alloys."

PEARCE, J. G.—"The Elasticity, Deflection and Resilience of Cast Iron."

PORTEVIN, A., E. PRÉTET and H. JOLIVET.—"Contribution to the Study of the Chemical Resistance of Various Special Steels."

REES, S. H.—"The Properties of Non-Hardenable Alpha-Iron Steels."

ROLLASON, E. C.—"Some Effects of Cold-Rolling on the Intergranular Corrosion of the 18/8 Stainless Steels."

RUSSELL, G. A. V.—"Flexibility as a Factor in the Economic Exploitation of Rolling-Mills and some Technical Means for its Realisation."

SAŘÉK, J.—"Principles of the Design of Blast-Furnace Lines."

SYKES, C., and J. W. BAMPFYLDE.—"The Physical Properties of Iron-Aluminium Alloys."

THYSSEN, H.—"The Influence of Silicon and Aluminium on the Resistance of Cast Iron to High Temperatures."

Volume XXIII. of the Carnegie Scholarship Memoirs was published in 1934, and contained the following Reports:

BAUKLOH, W., and R. DURRER.—"The Primary Reaction of Metallic Oxides with Solid Carbon."

ERICSON, G.—" Determination of the Change in Volume of Iron on Solidification."

FRANCIS, E. L.—" Studies of the Wire-Drawing Process. VII.—The Application of Metallic Coatings as Lubricants, with Special Reference to the Drawing and Properties of a Lead-Coated Austenitic Chromium-Nickel Steel."

JONES, B.—" Investigations into the Nitrogen-Hardening of Steels. Part III. —The Nitriding of Steels Containing a Low Alloy Content of Chromium and Aluminium at Various Temperatures (including Results obtained by Two-Stage Nitriding)."

JONES, B.—" Investigations into the Nitrogen-Hardening of Steels. Part IV. —The Nitriding of High-Chromium and Austenitic Steels at Various Temperatures."

MITSCHE, R.—" The Flotation of Non-Metallic Inclusions in Molten Metals."

NORBURY, A. L., and E. MORGAN.—" Aluminium-Manganese-Silicon Cast Irons."

SCOTT, A. T.—" The Fatigue Strength of Arc-Welded Butt Joints."

PUBLICATIONS.

The usual two volumes of the Journal, the monthly Bulletin, the Second Report of the Corrosion Committee, the First Report of the Blast-Furnace Practice Sub-Committee, a Report on Blast-Furnace Linings, and a volume of Carnegie Scholarship Memoirs were published during the year. As from the August issue, the Bulletin of Technical Abstracts, known as " Iron, Steel and Industrial Fuel," which is published in conjunction with the British Iron and Steel Federation, was made available, free of charge, to members of the Institute.

ANDREW CARNEGIE RESEARCH SCHOLARSHIPS.

Grants were made by the Council in 1934 to the following candidates :—

M. ALEXANDER (University College, Swansea), £100 for a further study of the influence of gases on the position of blow-holes in steel ingots.

D. G. DAVIES (University College, Swansea), £100 for a further study of the influence of gases on the position of blow-holes in steel ingots.

R. B. MEARS (Cambridge University), £100 for a study of the effect of composition on the corrosion velocity and corrosion probability of steel.

T. RAINE (Sheffield University), £100 for an investigation of the determination of oxygen in steel.

E. M. TRENT (Sheffield University), £100 to investigate the manufacture of clean steel.

H. WENTRUP (Technical High School, Berlin), £100 in aid of an investigation of the equilibrium $Mn + FeS \rightleftharpoons MnS + Fe$ in iron melts containing carbon and the influence of silicon and phosphorus upon it.

L. E. ADAMS (College of Technology, Manchester), £50 for a study of the effect of torsional overstrain on the physical properties of steels suitable for helical springs.

C. L. SHAPIRO (Harvard University), £50 in aid of his investigation of the physical and chemical properties of a constituent obtained by special heat treatment of spheroidized steels.

Carnegie Gold Medal.

For the year 1934, no award of the Carnegie Gold Medal was made.

Williams Prize.

For the year 1934, no award of the Williams Prize was made.

Library.

During the past year the collection of books in the Library has been enriched by the addition of a number of important works on metallurgy; many of these were presented, and the Council take this opportunity to extend thanks, on behalf of the members, to the donors.

In view of the many demands made upon the Library, its upkeep is of the greatest importance, and while every endeavour is made to keep the collection of literature, both text-books and periodicals, up to date so far as the Institute's financial resources permit, the Council wish to urge upon authors the claims of the Institute to the presentation of copies of works on ferrous metallurgy and the iron and steel industry. A notice of all books presented to the Library is published in the Journal of the Institute.

The work of the Loan Department of the Library increased greatly during the year, owing to the number of works borrowed by the members. Much help has also been rendered to various Government departments, research laboratories and iron and steel works by the loan of volumes. In addition, volumes have been loaned to a large number of students through the National Central Library.

Attention is drawn to the fact that the majority of the articles abstracted in Section II. of the Journal are filed in the Library and are available for loan. Photographic copies of articles can be supplied under certain conditions, and this service should prove very valuable to the overseas members.

Members are reminded that in addition to the Institute's Library, the valuable collection of scientific works included in the Science Library, South Kensington, is available to them for reference, by kind permission of the Director of the Science Library.

A list of the additions made to the Library is issued quarterly, and copies will be sent to members on request.

In co-operation with the British Iron and Steel Federation, the Institute has made arrangements to house and incorporate with the Library collection a number of works purchased under a grant to the Iron and Steel Industrial Research Council from

the Carnegie Trust. These volumes are available for consultation by and loan to the members of the Institute.

Members seeking information on technical subjects are invited to make use of the Enquiry Bureau. The number of enquiries from home and abroad dealt with during the past year is an indication of the value of this service.

Technical Committees.

The close connection between the Institute and the Iron and Steel Industrial Research Council was maintained and extended during the year. The Institute was officially represented on the Research Council by Mr. F. W. Harbord, C.B.E., Dr. W. H. Hatfield and the Secretary, and in addition seven of the remaining fifteen members of the Research Council were, at December 31, 1934, Members of Council of the Institute.

It is confidently anticipated that this close connection will prove of mutual benefit and of increasing value in encouraging research in the industry.

In addition to the Heterogeneity of Steel Ingots and Corrosion Committees, arrangements were made for the Steel Castings Research Committee to be a Joint Committee of the Iron and Steel Institute and the Iron and Steel Industrial Research Council; similarly it was contemplated that the Alloy Steel Research Committee should operate as a Joint Committee.

Committee on the Heterogeneity of Steel Ingots.—The Committee, of which Dr. W. H. Hatfield is the Chairman, suffered a severe loss in the sudden death of Mr. J. H. S. Dickenson, who had acted as Vice-Chairman since its formation, and had taken a most active part in its work. By the death of Mr. E. H. Saniter, the Committee was deprived of the helpful and stimulating criticism of a universally respected metallurgist. Mr. A. P. Hague resigned from the Committee in December. (In February, 1935, Dr. T. Swinden was appointed Vice-President and Mr. H. H. Burton was nominated a member of the Committee.)

Seven meetings of the Committee were held during the year, including a joint meeting with the Open-Hearth Committee of the Iron and Steel Industrial Research Council.

Members of the Committee had the opportunity, through the kindness of Monsieur Clerf, of the Société Anonyme des Hauts Fourneaux, Forges et Aciéries de Denain et d'Anzin, to observe the manufacture of rimming steel by the basic Bessemer process, and, subsequently, to make a detailed examination of two ingots, selected by them and sent over to this country. Detailed examinations have also been made of an ingot of austenitic 18/8 chromium-nickel acid-resisting steel as well as of a 12 per cent. manganese steel bloom.

The joint meeting with the Open-Hearth Committee made apparent the important part which oxygen appears to play in many of the problems under investigation by these Committees. As a result, arrangements were made for the work on oxygen determinations at the National Physical Laboratory and at Sheffield University to be intensified.

The work at Swansea University on the effect of gases in steel was continued.

A further result of the joint meeting of the two Committees was the setting up in November of an Ingot Moulds Sub-Committee consisting of representatives of both Committees and of the British Cast Iron Research Association, with Mr. R. H. Myers as Chairman. Two meetings of the Sub-Committee were held.

A questionnaire designed to determine the priority of major factors affecting ingot mould life was prepared and will be issued to the industry; practical tests at works have been begun. It is the object of the Sub-Committee to study factors affecting ingot mould life and the effect of design on steel quality.

Corrosion Committee.—The late Mr. J. H. S. Dickenson was Vice-Chairman of this Committee, of which Dr. W. H. Hatfield is the Chairman, and by his death the Committee lost a most valued member. Dr. L. A. Jordan, Chairman of the Research Association of British Paint, Colour and Varnish Manufacturers, joined the Committee in March, in order to give assistance particularly in matters relating to paints. Principal C. A. Edwards, F.R.S., joined the Committee in November, in order to facilitate collaboration with the South Wales Siemens Steel Association Research Committee. (Dr. T. Swinden was appointed Vice-Chairman and Mr. H. H. Burton was invited to join the Committee in February, 1935.) On November 1, Dr. T. A. Banfield was engaged as assistant to the Committee's Investigator, Dr. J. C. Hudson.

Seven meetings of the Committee were held during the year, and the Second Report to the Iron and Steel Industrial Research Council (Special Report No. 5) was presented at the Annual Meeting of the Institute. In view of the full programme of work before the Committee it was decided that annual reports should be published in future.

Relations with foreign organisations studying corrosion were maintained, and preliminary steps were taken to secure their co-operation in studying the effect of climate on atmospheric corrosion.

The investigation of atmospheric corrosion being carried on by Dr. Hudson was continued, and a preliminary report was prepared on the first series of specimens removed from the Sheffield station after one year's exposure.

Steels for Part III. of the tests, dealing with the atmospheric corrosion of higher tensile alloy steels containing small additions

of copper, chromium and other elements, were prepared during the year and were exposed early in 1935.

Tests were also carried out on synthetic wrought iron made by the Aston Byers process; the tests on paints of different compositions were continued, and a report was prepared on steel sleepers which were examined after 2½ years' service.

Tests to explore the effect of ageing on the properties of mild-steel wire were concluded, and a second series of corrosion tests on wire by measurement of the decrease of the breaking load was undertaken.

The work on marine corrosion was extended. The lighter *Cactus* was built under careful inspection from plates of known history prepared under various conditions, and arrangements were made for frequent inspection and observation. An inspection of the *S.S. Hardingham* was carried out on behalf of the Committee, and arrangements were also made for plates to be built into a new Admiralty trawler. Pontoons forming a landing stage at Gosport were inspected and plans discussed for the erection there of a preliminary series of marine tests on frames.

The Committee were in close touch with the Low Temperature Research Station at Cambridge, whose work on the study of the effect of fruit juices on steels such as are used for making tinplate cans is of interest to the Committee. The Committee undertook to arrange for suitable samples of steel to be made available to the Low Temperature Research Station.

The Laboratory Research Sub-Committee, formerly known as the Laboratory Tests Sub-Committee, of which Dr. U. R. Evans is Chairman, held two meetings, and made recommendations to the Committee for a possible programme of fundamental research work.

Steel Castings Research Committee.—The Committee was constituted a Joint Committee of the Institute and the Iron and Steel Industrial Research Council in November. Dr. H. Moore, C.B.E., expressed his desire to retire from the Chairmanship, owing to the fact that he was no longer primarily concerned with ferrous products, but was prevailed upon to remain a member of the Committee. Mr. W. J. Dawson was elected Chairman, and Mr. H. H. Burton was nominated a member of the Committee; steps were also taken for further increasing the membership. Mr. Hague resigned his membership, and the Committee have suffered a most grievous loss through the death of Mr. J. H. S. Dickenson.

An extended programme of work to be undertaken during the coming year was considered.

The Council wish to acknowledge the strong financial assistance and support which these Committees have received from the

British Iron and Steel Federation, the Iron and Steel Industrial Research Council, and the British Steelwork Association; they wish also to take this opportunity of expressing their thanks to those Departments of His Majesty's Government with whom they have been in touch, to leading manufacturers in the steel and other industries and to the Metallurgical Departments of the National Physical Laboratory and various Universities, for their valuable assistance and co-operation, without which the researches of these Committees could not have been prosecuted. They are particularly indebted to those who have placed at their disposal facilities for making practical experiments on sleepers, ships, &c., and who have offered, free of cost, valuable quantities of different steels for testing. They gratefully acknowledge the assistance which has been given by many individual research workers and others in time and labour.

The Worshipful Company of Blacksmiths.

During the past year, no nominations for admission to the Worshipful Company of Blacksmiths were made by the Council.

Appointment of Representatives.

The following is a list of the Institute's representatives on various governing bodies and committees for the year 1934; it has been brought up to date to April 1, 1935:

Royal Society, General Board for Administering Government Grants for Scientific Investigations: The President.

National Physical Laboratory,
General Board: Dr. A. McCance, Dr. W. H. Hatfield.
Alloys of Iron Research Committee: Mr. F. W. Harbord, C.B.E.

Imperial College of Science and Technology, Board of Governors: Mr. B. Talbot.

Science Museum, Advisory Council: Sir Harold Carpenter, F.R.S.

Royal School of Mines, Advisory Board: Mr. F. W. Harbord, C.B.E.

Sheffield University, Court of Governors: Sir Robert Hadfield, Bt., F.R.S.

Department of Scientific and Industrial Research: Grey and Malleable Cast Iron Research Committee: Professor T. Turner.

Iron and Steel Industrial Research Council: Mr. F. W. Harbord, C.B.E., Dr. W. H. Hatfield, Mr. K. Headlam-Morley.

BRITISH STANDARDS INSTITUTION,
Engineering Divisional Council E/–: Dr. W. H. Hatfield, Mr. E. H. Saniter (deceased), Mr. J. Bird.
Technical Committee ME/22, Marking and Colouring of Foundrymen's Patterns: Mr. F. W. Lewis.
Technical Committee ME/25, Testing of Thin Metal Sheet and Strip: Dr. T. Swinden.
Technical Committee ME/35, Cast Iron: Mr. H. B. Toy.
Iron and Steel Industry Committee IS/–: Mr. E. H. Saniter (deceased).
Technical Committee SH/5, Ships Materials: Mr. E. J. George.
Chemical Engineering Divisional Council: Mr. E. F. Law.
Technical Committee ME/32, Engineering Symbols and Abbreviations: Mr. E. H. Saniter (deceased).
Technical Committee B/16, Breeze and Clinker Slabs: Mr. F. W. Harbord, C.B.E.
Technical Committee EL/28, Fans: Mr. A. F. Webber.
Public Works Industry Committee PW/–: Mr. J. Henderson.
Technical Committee PW/34, Portland Blast-Furnace Cement: Mr. F. W. Harbord, C.B.E.
Technical Committee IS/6, Steel Castings: Dr. R. H. Greaves.
Technical Committee IS/7, Alloy Steels: Dr. R. H. Greaves.
Technical Committee IS/8, Creep Properties: Dr. W. H. Hatfield.
Sub-Committee M/33/7, Protective Glasses for Welders and Industrial Purposes: Dr. C. H. Desch, F.R.S.

BRITISH CAST IRON RESEARCH ASSOCIATION: Professor T. Turner.

BRITISH REFRACTORIES RESEARCH ASSOCIATION, Council: Sir Robert Hadfield, Bt., F.R.S., Mr. F. W. Harbord, C.B.E.

LLOYD'S REGISTER OF SHIPPING, Technical Committee: Mr. John Craig, C.B.E., Mr. J. S. Hollings.

BRITISH CORPORATION REGISTER OF SHIPPING AND AIRCRAFT, Committee of Management and Technical Committee: Dr. A. McCance.

SCHOOL OF METALLIFEROUS MINING (CORNWALL), Board of Governors: Professor H. Louis, M.A., D.Sc.

METALLIFEROUS MINING AND QUARRYING INDUSTRIES, Advisory Committee: Professor H. Louis, M.A., D.Sc.

EMPIRE COUNCIL OF MINING AND METALLURGICAL INSTITUTIONS: Mr. F. W. Harbord, C.B.E., Professor H. Louis, M.A., D.Sc.

INSTITUTE OF FUEL, Council: Mr. F. W. Harbord, C.B.E.

BRITISH ASSOCIATION, Fuel Economy Committee: Sir Robert Hadfield, Bt., F.R.S.

HONG KONG UNIVERSITY, Home Committee: Sir Robert Hadfield, Bt., F.R.S.

LIVERPOOL UNIVERSITY, Court of Governors: Sir W. Peter Rylands.

BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION, Sub-Committee J/E, Joint Committee, Steels for High Temperatures: Dr. W. H. Hatfield, Dr. T. Swinden.

CITY AND GUILDS OF LONDON INSTITUTE,

Advisory Committee on Metallurgy: Sir Harold Carpenter, F.R.S.

Examiner in Iron and Steel Manufacture: Professor W. H. Merrett.

CONSTANTINE COLLEGE, Advisory Committee: Mr. E. W. Jackson.

MECHANIZATION BOARD (late Mechanical Warfare Board) (Army Council): Mr. F. W. Harbord, C.B.E.

RAMSAY MEMORIAL LABORATORY, Advisory Committee: Mr. F. W. Harbord, C.B.E.

ASSOCIATION OF SCIENTIFIC AND TECHNICAL INSTITUTIONS, Council: Sir Robert Hadfield, Bt., F.R.S.

THE IRON AND STEEL INSTITUTE.
BALANCE SHEET, 31ST DECEMBER, 1934.

Sundry Creditors :— LIABILITIES. ASSETS.

THE IRON AND STEEL INSTITUTE.

BALANCE SHEET, 31st DECEMBER, 1934.

LIABILITIES.

Sundry Creditors :—				
Office Rent, &c.			£208 12 1	
Journal Printing, No. I., 1934			760 18 5	
Telephone Calls			3 18 3	
Office Furniture			5 0 6	
Library Books			3 5 3	
Library Sales			4 0	
Printing and Stationery			94 7 10	
Bulletins			16 2 0	
Library Postage Deposits			9 9 7	
Ingot Committee			9 4	
Income Tax Recovered :—				
Williams Prize Fund	26 5 0			
Carnegie Scholarship Fund	289 18 10			
		316 3 10		
				1,418 11 1
Subscriptions in Advance :—				
Home Members		6 6 0		
Foreign Members		42 0 6		
Associate Members		2 2 0		
				50 8 6
Journal Sales :—				
Amount in advance, 1935		29 0 0		
Received on account, No. II., 1934		222 16 3		
				251 16 3
Suspense Account :—				
Special Appeal Contributions held in Suspense				1,000 0 0
Iron and Steel Institute :—				
Capital and Reserve Account		24,806 1 4		
Deduct Loss on Sale of L. & N.E. Railway Stock		933 9 0		
		23,872 12 4		
Add Autumn Meeting Fund		1,200 0 0		
		25,072 12 4		
Less Accumulated Excess of Expenditure over Income as at 1st January, 1934	142 14 6			
Less Excess of Expenditure over Income for year to 31st December, 1934	155 5 8			
		298 0 2		
				24,774 12 2
Life Composition Fund :—				
As at 1st January, 1934		3,306 5 3		
Add Compounded during year		28 7 0		
		3,334 12 3		
Less Loss on Sale of L. & N.E. Railway Stock		224 10 1		
				3,110 2 2
				£30,605 10 2

ASSETS.

Sundry Debtors:—				
Subscriptions in arrear				Not valued.
Journal Sales		£203 8 11		
Do. 10-year Index		2 0 0		
Amount due from Carnegie Research Fund		174 9 8		
Bulletins Account		125 0 0		
Telephone Deposit		1 0 0		
Miscellaneous		2 7 6		
Annual Meeting		2 5 0		
International Testing Association		2 6 7		
Welding Symposium		15 2		
Research Committees		122 5 0		
				635 17 10
Payments in Advance :—				
Insurance		4 5 6		
Library Books		23 8 0		
Staff Superannuation Fund		110 10 10		
Telephone		10 18 0		
Insurance (Corrosion Committee)		6 2 6		
				155 4 10
Stock of Journals				Not valued.
Office Furniture and Library				Not valued.
Investments at cost per Schedule :—				
General Fund				23,872 12 4
(The Market value of these Securities at 31st December, 1934, was £29,158 12*s.* 1*d.*)				
Cash at Bank and in Hand :—				
Current Account		970 19 3		
Secretary's Account		144 10 5		
Deposit Account		1,700 0 0		
Deposit Banque de Plovdiv, Bulgaria		5 5 0		
Cash at Office		10 18 4		
				2,831 13 0
Life Composition Fund: —				
Investments at cost per Schedule		3,081 15 2		
Cash at Bank		28 7 0		
				3,110 2 2
(The Market value of these Securities at 31st December, 1934, was £3,420 12*s.* 3*d.*)				
				£30,605 10 2

GENERAL FUND.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1934.

INCOME.

To Entrance Fees			£193 4 0
„ Annual Subscriptions :—			
Members, Home—Current	3,189 7 6		
Arrears	194 6 0		
		3,383 13 6	
Members, Foreign—Current	1,536 8 7		
Arrears	80 9 7		
		1,616 18 2	
Associates		56 2 6	
„ Journal Sales		1,117 6 5	
„ Interest on Investments (*less* Tax) :—			
General Fund	929 10 4		
Life Composition Fund	96 11 9		
Bessemer Medal Fund	12 4 0		
		1,038 6 1	
„ Interest on Deposit		4 2 10	
„ Sundry Receipts		2 16 6	
„ Income Tax Recovered, 1933/34 :—			
General Fund	113 3 4		
Life Composition Fund	17 4 5		
Bessemer Medal Fund	4 0 0		
		134 7 9	
„ Autumn Meeting	1,204 1 11		
Less Transferred to Capital and Reserve Account	1,200 0 0		
		4 1 11	
„ Balance, being Excess of Expenditure over Income carried down		2,187 12 8	
		£9,738 12 4	

To Special Appeal Fund :—		
Contributions received during 1934		£2,032 7 0
„ Excess of Expenditure over Income carried to Balance Sheet		155 5 8
		£2,187 12 8

EXPENDITURE.

By Salaries (including Pensions and Overtime)			£4,094 17 11
„ Staff Superannuation Fund			195 12 8
„ Office Rent, Cleaning, &c.			1,150 2 6
„ Library Books, Binding, &c.			118 17 2
„ Office Furniture			203 11 4
„ Annual Meeting			150 7 3
„ Journal Publishing Expenses :—			
Printing and Paper	1,361 17 11		
Abstracts	184 12 11		
Postages	195 13 8		
		1,742 1 6	
„ Ten-year Index Publishing Expenses	649 15 2		
Less Sales	163 16 3		
		485 18 11	
„ Stationery and Printing (including copies of Papers)		398 4 4	
„ Printing of Blast Furnace Reports :—			
Expenditure incurred during year	245 0 3		
Less Contribution by British Iron and Steel Federation	122 5 0		
		122 15 3	
„ Expenses of Corrosion Committee		392 4 3	
„ Expenses of Steel Ingots Committee		133 2 7	
„ Postages and Receipt Stamps		124 8 7	
„ Travelling Expenses		31 16 11	
„ Insurance		28 3 8	
„ Telephone Rentals and Calls		42 0 9	
„ Auditors' Fees		31 10 0	
„ Bessemer Medal		24 2 6	
„ Compassionate Allowance		30 0 0	
„ Bulletins Account		12 8 2	
„ Office Disbursements and Sundry Expenses		85 4 1	
„ Grants :—			
British Electrical and Allied Industries Research Association	50 0 0		
British Refractories Research Association	25 0 0		
British Standards Institution	50 0 0		
International Association for Testing Materials	5 0 0		
British Cast Iron Research Association	10 10 0		
		140 10 0	
		£9,738 12 4	
By Balance brought down		£2,187 12 8	
		£2,187 12 8	

						£2,187	12	8

						£2,187	12	8

ANDREW CARNEGIE RESEARCH SCHOLARSHIP FUND.

BALANCE SHEET, 31st DECEMBER, 1934.

LIABILITIES.								
Sundry Creditors :—								
Grants					£262	10	0	
Amount due to General Fund					174	9	8	
Auditors' Fee					10	10	0	
Tibor Ver's A/c					31	4	9	
								£478 14 5
Amount of Original Fund ($100,000)					21,241	5	6	
Add Amounts since Capitalised					2,912	9	6	
					24,153	15	0	
Add Surplus Income as at 1st January, 1934			1,437	11	7			
Add Excess of Income over Expenditure for year ended 31st December, 1934			107	1	1			
					1,544	12	8	
								25,698 7 8
								£26,177 2 1

ASSETS.								
Investments at Cost, per Schedule								£25,355 16 10
(The Market value of these Securities at 31st December, 1934 was £33,460 3*s.* 9*d.*)								
Cash at Bank :—								
On Current Account								500 10 11
Payments in advance								30 15 6
Sundry Debtors :—								
General Fund for Income Tax recovered								289 18 10
								£26,177 2 1

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1934.

INCOME.								
To Interest on Investments						£1,033	11	8
,, Income Tax Recovered, 1933/1934						289	18	10
,, Interest on Deposit						1	8	9
						£1,324	19	3

EXPENDITURE.								
By Scholarship Grants						£728	3	0
,, Printing Memoirs vol. 22						352	10	0
,, Salaries						104	0	0
,, Sundries							16	0
,, Legal Expenses						2	9	2
,, Audit Fee						10	10	0
,, Medal						19	10	0
,, Excess of Income over Expenditure carried to Balance Sheet						107	1	1
						£1,324	19	3

WILLIAMS PRIZE FUND.

BALANCE SHEET, 31st DECEMBER, 1934.

LIABILITIES.				ASSETS.			
Capital Account representing the Market Value of £3,000 3½ per cent. Conversion Loan at 21st September, 1926, when Fund was inaugurated		£2,220 0 0		£3,000 3½ per cent. Conversion Loan (at Cost)	£2,220 0 0		
Income and Expenditure Account :—				Cash at Bank	132 7 7		
Balance as at 1st January, 1934	40 10 1					£2,352 7 7	
Add Excess of Income over Expenditure for year to 31st December, 1934	118 2 6			(Market Value of this Security at 31st December, 1934, was £3,330.)			
		158 12 7		Iron and Steel Institute :—			
		£2,378 12 7		Income Tax Recovered, 1933/34		26 5 0	
		£2,378 12 7				£2,378 12 7	

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1934.

INCOME.		EXPENDITURE.	
To Interest on 3½ per cent. Conversion Stock	£91 17 6	By Excess of Income over Expenditure carried to Balance Sheet	£118 2 6
„ Income Tax Recovered, 1933/34	26 5 0		
	£118 2 6		£118 2 6

THE IRON AND STEEL INSTITUTE.

SCHEDULE OF INVESTMENTS AT 31ST DECEMBER, 1934.

(showing Nominal Values, Cost Values and present Market Values.)

Nominal Value.	Nature or Security.	Market Price, 31/12/1934.	Cost Price.
GENERAL FUND OF THE INSTITUTE.			
£2,197 7 0	3½ per cent. War Stock	£2,389 12 4	£2,161 0 8
324 7 4	3½ per cent. Conversion Loan	360 0 11	231 1 0
447 0 0	Southern Railway 4 per cent. Debenture Stock	511 16 4	449 2 4
1,872 0 0	London and North Eastern Railway 4 per cent. 2nd Guaranteed Stock	1,806 9 7	2,148 13 3
2,241 0 0	London and North Eastern Railway 4 per cent. 1st Guaranteed Stock	2,297 0 6	2,431 14 5
1,500 0 0	Buenos Ayres Great Southern Railway 4 per cent. Debenture Stock	1,305 0 0	1,594 12 9
1,000 0 0	Calcutta Bonds 4 per cent., 1939	1,050 0 0	982 10 0
800 0 0	Bombay 4 per cent. Bonds, 1939	836 0 0	809 0 0
2,954 1 0	4 per cent. Consolidated Stock	3,478 7 11	3,175 18 1
437 0 0	London and North Eastern Railway 3 per cent. Debenture Stock	371 9 0	376 12 5
12,242 19 3	4 per cent. Funding Loan, 1960/90 (transferred from Special Purposes Fund)	14,752 15 6	9,512 7 5
		£29,158 12 1	£23,872 12 4
LIFE COMPOSITION FUND.			
£386 6 0	3½ per cent. Conversion Loan	428 15 11	304 10 0
1,330 0 0	London and North Eastern Railway 3 per cent. Irredeemable Debenture Stock	1,130 10 0	1,254 17 6
594 0 0	London Passenger Transport Board 4½ per cent. "A" Stock (July, 1933)	739 10 7	638 6 1
130 4 8	3½ per cent. Conversion Loan	144 11 3	137 11 0
143 6 0	3½ per cent. War Loan	155 16 9	146 10 7
681 13 0	4 per cent. Funding Loan	821 7 9	600 0 0
		£3,420 12 3	£3,081 15 2

CARNEGIE FUND OF THE INSTITUTE.

SCHEDULE OF INVESTMENTS AT 31ST DECEMBER, 1934.

(showing Nominal Values, Cost Values and present Market Values.)

Nominal Value.	Nature of Security.	Market Value. 31/12/1934.	Cost Price.
£6,897 14 11	War Stock 3½ per cent.	£7,501 5 11	£6,895 16 6
2,693 12 0	Conversion Loan 3½ per cent.	2,989 17 11	2,006 19 0
227 9 4	Local Loans 3 per cent.	221 4 3	202 10 0
2,300 0 0	India Stock 3½ per cent, 1931	2,277 0 0	1,600 2 9
2,560 4 0	India Stock 3 per cent., 1931	2,380 19 8	1,525 3 3
2,250 0 0	North Eastern Electric Supply Co. 3½ per cent.	2,317 10 0	2,261 10 0
1,500 0 0	Great Western Railway 4 per cent. Debenture	1,732 10 0	1,204 5 3
2,000 0 0	London Midland and Scottish Railway 4 per cent. Debenture	2,170 0 0	1,693 0 6
1,312 0 0	London and Northern Eastern Railway 4 per cent. 1st Guaranteed	1,344 16 0	880 11 11
5,000 0 0	London and North Eastern Railway 4 per cent. Debenture	5,425 0 0	3,540 8 5
6,000 0 0	London and North Eastern Railway 3 per cent. Debenture	5,100 0 0	3,545 9 3
		£33,460 3 9	£25,355 16 10

INVESTMENT ON ACCOUNT OF WILLIAMS PRIZE FUND.

£3,000 0 0	3½ per cent. Conversion Loan	£3,330 0 0	£2,220 0 0

BESSEMER MEDAL FUND.

Trustees: Sir Harold Carpenter, Lord Airedale and Francis Samuelson, Esq.

£400 0 0	London Midland and Scottish Railway 4 per cent. Debenture Stock	£434 0 0	— — —

(*Signed*) JAMES HENDERSON, *Hon. Treasurer.* K. HEADLAM-MORLEY, *Secretary.*

I have examined the foregoing Balance Sheets and Income and Expenditure Accounts with the Books and Vouchers of the Institute and certify them to be correct. I have also verified the Balances at the Bankers and the Securities for the Investments shown above.

23 QUEEN VICTORIA STREET,
LONDON, E.C.4.
13th April, 1935.

W. B. KEEN,
Chartered Accountant.

Induction of the New President.

Mr. W. R. Lysaght, C.B.E., the retiring President, said that it was with regret that he reached the end of his two years as President of the Institute. He had enjoyed his term of office very much indeed. He had had the support not only of the Council, but of every member of the Institute. During the visit of the Institute to Sheffield the year before last the members met with the greatest help and support from everyone there and were received with extreme kindness, and during their visit last year to Belgium and Luxemburg they were also most hospitably entertained and nothing was lacking to make their visit a profitable and pleasurable one. Their friends in Belgium and Luxemburg opened their works to the members of the Institute on every occasion and showed them everything they had, and he thought it was desirable to place on record how grateful the members of the Institute were for what was done for them in those countries.

He was being succeeded as President by Sir Harold Carpenter, a most distinguished man, who would conduct the duties of President most ably. It was of interest to note that Sir Harold was a great-great-grandson of Henry Cort, who, as some of the members might recall, started puddling some hundred and fifty years ago, and so well did he do it that the methods then invented were still very largely in use. It was of great interest that the Institute could have a President who had, as one might say, iron in his blood.

[Mr. Lysaght then left the chair, which was taken, amid applause, by the new President, Sir Harold Carpenter, Ph.D., F.R.S.]

Mr. F. W. Harbord, C.B.E. (Past-President) said that it was with the very greatest pleasure that he proposed a vote of thanks to Mr. Lysaght for his valuable services in the Chair. Few Presidents had had such a long connection with the iron and steel industry and such a wide experience on the technical and on the commercial side as Mr. Lysaght. In addition to his very many other qualifications, the retiring President had that gift of the gods, a keen sense of humour, of which he had given evidence during his Presidency. All the members felt that in view of the many calls on his time they were greatly indebted to Mr. Lysaght for the amount of attention which he had given to the interests of the Institute. They were delighted to see him present in such excellent health, and to know that the somewhat serious illness which had threatened him in the early days of his Presidency had left no ill-effects. It was the sincere hope of

them all that Mr. Lysaght would continue for many years to enjoy the best of health and be able to assist in the guidance of the Institute and the industry with his wide knowledge of men and things and his sound judgment.

[The vote of thanks was carried by acclamation.]

Mr. W. R. LYSAGHT said he was very grateful that the vote of thanks had been proposed by Mr. Harbord. Mr. Harbord and himself were two of the oldest members of the Institute; he remembered Mr. Harbord nearly fifty years ago in Wolverhampton as one of the pioneers of the basic process. They were both young men in those days, but one could tell even at that time what an able and brilliant man Mr. Harbord was going to be. He had been a friend of the whole iron and steel trade throughout his career, and when at the Ministry of Munitions was the most sought-after man in the whole building.

Personally, he had been connected with the iron trade for nearly sixty years. He started puddling under Mr. Cort's process in 1874/5, and he had been in harness ever since. He had thoroughly enjoyed it; it was a fine, manly trade and he looked back on his work in it with pleasure. It was a great compliment and honour to him that towards the end of his life he had been chosen as President of the Institute; he would always remember the great happiness of his two years of office.

SIR HAROLD CARPENTER, F.R.S. (President), speaking from the Chair, said it was thirty-three years since he had attended his first meeting of the Institute in the old building of the Institution of Civil Engineers on the opposite side of Great George Street, in the year 1902. He had at that time recently been appointed to the National Physical Laboratory, and Sir Richard Glazebrook, the Director, suggested that he should go and see what the Iron and Steel Institute was like. He remembered sitting as a very humble member in the back row and seeing the Council come in. Mr. William Whitwell was President of the Council in that year, and he was glad to see present that day several members of Council who were present thirty-three years ago. The meeting started off with a lively paper by Professor Arnold, and that was followed by the liveliest discussion which he had ever heard in his life. He remembered Dr. Stead coming in with a large packet of books and papers and discussing the paper very vigorously. When he got back to Teddington he told Sir Richard Glazebrook that the Institute was the liveliest body he had ever attended, and that everybody said exactly what he thought. He was glad to think that the Institute still possessed those qualities.

It was a great privilege to him to follow Mr. Lysaght in the Presidential Chair. He would not say that Mr. Lysaght had made it too difficult for anyone else to follow him, but the best tribute he could pay to Mr. Lysaght's success as President was that he was finding it very difficult to follow him. He would like to thank Mr. Lysaght for the words he had used in introducing him to the meeting, and to thank his colleagues on the Council for the great honour they had done him in electing him to the Presidency.

Presentation of the Bessemer Gold Medal to Professor A. M. Portevin.

The President (Sir Harold Carpenter, F.R.S.) said that they had hoped to have with them that day His Excellency the French Ambassador, but unfortunately a previous engagement had prevented his attendance. The Institute was glad to welcome, however, M. le Vicomte du Halgouët, the French Commercial Attaché.

The Bessemer Gold Medal of the Iron and Steel Institute had been awarded this year to Professor A. M. Portevin, Director of the Institut de Soudure Autogène, Professor at the École Superieure de Fonderie, and at the École Centrale des Arts et Manufactures, Paris.

Professor Portevin obtained a Carnegie Scholarship in 1907, and the results of his investigation, which dealt with the constitution of special ternary steels, were published in the *Carnegie Scholarship Memoirs* in 1909. For that work he was awarded the Carnegie Gold Medal. He was elected a member of the Institute in 1910.

His early papers were concerned with a wide variety of problems in physical metallurgy, mostly connected, more or less directly, with the heat treatment of steel. His brilliant work in collaboration with A. M. Garvin, on the effect of rapid cooling on the temperature of the transformation in steel, was unquestionably one of the greatest steps ever made towards an understanding of the effect of heat treatment and of the function of alloying elements in steel. Since that paper was published (in 1919), he had continued to interest himself in the subject, and almost every year he had made further valuable contributions to it. Most of those papers had been published in the *Revue de Métallurgie*, which owed a great debt to Professor Portevin, because in addition to being one of its most valued contributors he was its General Secretary and Vice-President of its Editorial Committee. He was universally regarded as one of the greatest living authorities on heat treatment, and those who had studied his May Lecture to the Institute of Metals on the phenomena of

quenching and tempering in alloys would realise that the reputation was thoroughly deserved.

Although heat treatment had always been, he thought, Professor Portevin's favourite field of research, he had carried out many valuable investigations on other subjects. He would like to mention four recent papers which would illustrate the wide scope of his interests. There was, first, the important paper in collaboration with P. Bastien, on the castability of ternary alloys, which was published last year by the Institute of Metals. Then came his work in collaboration with R. Castro on the determination of oxygen and oxides in steel, published in 1932 in the *Revue de Métallurgie*. Next, there was the paper published two years ago in the *Journal of the Iron and Steel Institute* on inclusions in steel—a paper which contained an excellent discussion of the physical chemistry of steel making—and finally he might mention Professor Portevin's famous research in collaboration with E. Prétet and H. Jolivet on high-temperature oxidation and scaling, published in 1934, also in the *Journal* of the Institute.

Up to the present time there had been sixty-seven awards of the Bessemer Gold Medal, and twenty-five of those had been made to distinguished foreign metallurgists. No less than eight of those were Frenchmen: Henri Schneider, Henri de Wendel, Floris Osmond, Alexandre Pourcel, Henri Le Chatelier, Pierre Martin, Charles Frémont and Eugène Schneider.

Professor Portevin accordingly became the ninth representative of that illustrious band of workers. It would, he thought, be conceded on all hands that he was worthy to take his place with them.

Four years ago, when he himself obtained the Bessemer Medal, Professor Portevin wrote to congratulate him, a letter which he greatly appreciated. In replying to Professor Portevin, he ventured to express the hope that it would not be long before Professor Portevin himself obtained the same honour, and this day saw the fulfilment of that hope. It added greatly to his pleasure that he should be the one to hand the Medal to Professor Portevin on behalf of the Council.

[The President then, amid applause, presented the Bessemer Gold Medal to Professor Portevin.]

Professor A. M. PORTEVIN said, in reply, that in 1909, at a meeting of the Institute, the late Sir Hugh Bell had presented him with the Carnegie Gold Medal, which had been not only a source of profound satisfaction to him, but a valued encouragement to pursue his researches in metallurgical science. That presentation occurred at an Autumn Meeting at which he came

to learn of the remarkable work which Professor Carpenter had done. At that time he had no idea that twenty-six years later he would have the signal honour of receiving from Sir Harold Carpenter the Bessemer Gold Medal, which was not only the highest award which the Institute could give, but also the highest which any metallurgist could receive.

He would like to thank His Excellency M. du Halgouet, the representative of the French Ambassador, for being good enough to be present and thus increase, if possible, the pleasure which the occasion gave him.

He was happy to express to the President, to the Members of Council and to all his colleagues in the Institute, his profound thanks for the supreme distinction conferred upon him, which would remain the honour and the crown of his career. Not only was there attached to it the great name of Bessemer, but also it had been presented in the past to the most illustrious metallurgists of the entire world. In particular, it was with emotion and gratitude that he recalled several of those whose advice and support had been so valuable to him at the commencement of his career, and notably Floris Osmond, one of the illustrious founders of the science of metallography; Alexandre Pourcel, who applied thermo-chemistry to metallurgical reactions and made such important and decisive improvements in the processes of steel manufacture; Henri Le Chatelier, who introduced physico-chemical methods and the laws of mechanical chemistry into metallurgy, and who was at the same time one of the protagonists of the application of science to industry, of which the marvellous technical results were now apparent.

There were, in fact, few industries which offered a more remarkable example than did metallurgy, of the profit which could be gained by the utilisation of scientific information, methods and laws. In fact, a special branch of science had been created which in France was called metallography and in Great Britain physical metallurgy.

It would seem that, in so far as its practical progress was concerned, metallography, at least in France, followed the opposite direction to that of the metal itself during its industrial existence. Metallography was taken up in the first place by the users and workers of steel, preoccupied in the first place by the relations between the constitution and structure on the one hand, and the properties and uses on the other, and then seeking to make more precise the mechanism and the laws of thermal and mechanical treatment which had such an important repercussion on the properties of the metal. Research was then taken up by the makers of special steels and of steels of high quality, where the operations had to be carried out in accordance with work done in the laboratory. That raised the complex problem of the

quality of steel and the relation between quality and the conditions of manufacture, and this brought in a number of considerations and factors which were often difficult to define and to study—primary crystallisation, dendritic segregation, solid inclusions and so on.

Finally, research laboratories had been set up in the big steelworks which desired to improve the properties of their products, and which borrowed from special metallurgy some of its methods to produce steels which were intermediate between the ordinary steels and the special steels.

This progress was also that which he himself had been led to follow in his own work, passing from mechanical and physico-chemical experiments to thermal and mechanical treatments, and then to the study of impurities in steel and inclusions and heterogeneity. What he had been able to accomplish in those directions was due to the assistance of collaborators who worked with him and whom he wished to associate fully with the great honour which had been done him that day. He mentioned particularly the names of Garvin, Bastien, Castro, Prétet and Jolivet. His work had also been greatly assisted by the sympathy, the interest and the friendship shown him by several holders of the Bessemer Gold Medal, and he had pleasure in referring to the names of Sir Robert Hadfield, Past-President, the late Dr. Rosenhain, who received the Medal at the same time as Eugène Schneider, Dr. Hatfield, whose name recalled to him several rapid and decisive results obtained during the war at his laboratory in Sheffield, and Sir Harold Carpenter, who, with his collaborators, had many times made known to the English public the work of the French school. He saw in the gesture which Sir Harold had just made a new mark of the friendship which he had always shown to the French school and for which the French school would remain profoundly grateful.

Papers Presented.

The Presidential Address was then delivered (*see* pp. 35-53), and the following papers were read and discussed :

"Third Report of the Corrosion Committee."—Being a Report of a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation to the Iron and Steel Industrial Research Council.

(*This Report is published separately as Special Report No.* 8. *A brief indication of its contents is given on p.* 516 *; the discussion and Committee's reply will be found on p.* 265.)

J. H. Andrew and G. T. Richardson : "An Investigation of Spring Steels."

J. Selwyn Caswell : "The Deflection of the Rolls in Plate, Sheet and Strip Mills."

G. A. HANKINS and H. R. MILLS: "Resistance of Spring Steels to Repeated Impact Stresses."

D. F. MARSHALL: "Further Determinations of the External Heat Loss of Blast-Furnaces." (Carnegie Research Paper.)

B. MATUSCHKA: "Non-Metallic Inclusions in Ferro Alloys."

T. E. ROONEY and A. G. STAPLETON: "The Iodine Method for the Determination of Oxides in Steel."

C. SYKES and H. EVANS: "Transformations in Iron-Aluminium Alloys."

J. WHITE, R. GRAHAM and R. HAY: "An Investigation into the Oxidising Power of Basic Slags."

J. H. WHITELEY: "An Effect of Oxygen and Sulphur on Iron in Scaling."

The following communications had been received and are printed in this *Journal*:

W. H. DEARDEN: "A Note on Reproducible Sulphur Prints."

E. JIMENO and I. GRIFOLL: "Electro-Chemical Interpretation of 'Cleaning.'"

CARNEGIE RESEARCH GRANTS.

The SECRETARY announced that applications for grants had been received from twenty candidates, and, after careful investigation of all the applications, the Council had decided that grants of the amounts stated below be awarded to the following applicants:

M. ALEXANDER (University College, Swansea).—£100 for the further study of the influence of gases on the position of blow-holes in steel ingots.

W. HOOK (Newcastle-on-Tyne).—£100 for a study of the pyrolysis of organic compounds with a view to determining the factors which favour graphite formation.

T. RAINE (Sheffield University).—£100 for an investigation of the determination of oxygen in steel.

G. T. RICHARDSON (University of Leeds).—£100 for an investigation of the influence of furnace atmospheres on steels.

J. B. VICKERS (Sheffield University).—£100 for an investigation of the determination of oxygen in steel.

G. BOOTH (Refractories Department, Sheffield University).—£100 for an investigation on basic refractories, with particular reference to their use in linings of induction furnaces.

R. GOODACRE and E. T. GILL (Messrs. Bruntons Research Laboratory, Musselburgh).—£100 for an investigation of some aspects of the fatigue properties of cold-drawn wires.

R. MITSCHE (Eisenhütteninstitut der Montanistischen Hochschule, Leoben).—£50 for the continuation of the research into the flotation of non-metallic inclusions and the application of the fluorescence microscope in the field of the non-metallic inclusions.

H. NIPPER (Institute of Foundry Practice, Aachen).—£50 for a research on recrystallisation tests on ferritic cast irons.

W. W. O. RUFF (Laboratories of the Bergische Stahl-Industrie, Remscheid).—£100 for a research on the running qualities of cast iron and steel under standardised pouring conditions.

A. A. TIMMINS (The British Cast Iron Research Association, Birmingham).—£50 for a research on the formation and decomposition of pearlite in cast iron.

CARNEGIE GOLD MEDAL AND WILLIAMS PRIZE.

The PRESIDENT announced that the Council had decided not to make any award of the Carnegie Gold Medal or of the Williams Prize.

PRESIDENTIAL ADDRESS.

ALLOYS—OLD AND NEW.

By Sir H. C. H. CARPENTER, D.Sc. F.R.S.

The word alloy is much in use to-day, and there is no doubt that in its most popular sense it implies something superior to a plain metal. Originally it meant the opposite to this, and scientifically it has always meant a metal containing more than one constituent, without regard to whether the effect of the other constituent is beneficial or otherwise. As I propose in this address to deal with alloys it is worth while to consider briefly the various meanings the term may have.

When the prevailing ideas about metals were dominated by the conception of abstract value, alloying was regarded mainly as a device for debasing the precious metals. To-day, when ideas about metals are principally concerned with the use to which they may be put, alloying is the most important method available for securing desirable properties. Thus, as the position of metals in our affairs has altered, so has the popular meaning of the term alloy. In its scientific sense the term takes no account of the reasons for the presence of the other elements, and this may be considered satisfactory, but neither does it take account of whether the mixture is intentional or accidental, and this is not so satisfactory, for it fails to distinguish between an alloy and a metal.

Scientifically a pure metal is a metallic element with a purity of 100 per cent. If everything else is an alloy then there is no practical distinction between a metal and an alloy, for although this purity has been closely approached in many metals, it has never been attained. With the knowledge available to-day it is obviously impossible to restrict the term alloy to metals containing more than a certain minimum amount of elements other than the basis metal, for extremely small amounts are known to have pronounced effects on their properties. Thus, if we are to make any distinction between metals at present available and alloys, it appears that we must take account of other factors besides chemical composition. I suggest therefore that while metal in its general sense means all metallic substances, in its particular sense it should be taken to mean an elementary metal in the condition of purity which can at present be attained. A pure metal would then mean one whose purity approached 100 per cent., while an impure metal would imply one of a lower degree of purity which would be more highly purified if the cost

was justified. An alloy in its scientific sense may include everything except a pure metal, but in its general sense it should signify a metal to which other elements are added or in which they are allowed to remain in order to obtain certain desirable properties at an economic price. In this address, except where otherwise indicated, I shall use this term to denote a metallic substance made by the intentional admixture of two or more elements with the object of obtaining properties not available in commercially pure metals, and shall thus be able to distinguish between metals, impure metals, alloys, and impure alloys

Historical.

As the preparation of the common metals in a condition of high purity is a very modern development, practically all the metals made until quite recently were alloys in the scientific sense. By way of contrast, however, comparatively few alloys were made by intentional admixture, and, speaking broadly, four stages may be recognised in the historical developments that have led to the present-day position.

(1) Before 3000 B.C. men were acquainted with native metals and the smelting of lead and copper. The copper produced by the early metallurgists contained impurities that varied with the locality, and these had the usual effect of hardening the metal. In this way metals that in a sense were alloys of copper with nickel, antimony, arsenic, zinc and tin were produced very long ago. The first step in the conscious preparation of alloys was taken, however, when these metallurgists came to realise that the production of a particularly useful kind of copper was associated with the presence in the ore of a heavy black or brown mineral—cassiterite—and started to mix this with their copper ore. Bronze appears to have been made in this way about 2000 B.C., but brass and copper-nickel-zinc alloys were also made by mixing the ores before the beginning of the Christian era.

(2) The second stage in development was the recognition of the constituent metals and the manufacture of alloys by mixing these. Bronze was made thus before 1500 B.C., but the method was not applied to other alloys until many centuries later. Zinc was not discovered until 1509, and brass was not made from copper and zinc until after that date. The discovery of nickel dates from 1751, and the copper-nickel-zinc alloys, that had been made in China by mixing ores long before the Christian era, were not made by mixing the metals until 1849.

The relation of the ferrous metals to the above stages in the development of alloys is rather uncertain, for although pure iron was not made until quite recently, it is difficult to say when

intentional alloying began. The earliest methods of extracting iron gave a product of variable composition, but in general it resembled what is now known as wrought iron. It was soon discovered, however, that by carburising, its strength and hardness could be substantially increased, particularly if the metal was quenched, and these operations were performed by the Egyptians as early as 900 B.C. This carburising appears to fall into the same category as the manufacture of alloys by mixing ores. So do those changes in the methods of smelting which resulted in the first production of cast iron in the 14th century. When it became known that the carburising of direct or wrought iron, and the blast-furnace smelting of cast iron, were methods of causing iron to absorb varying amounts of carbon, the preparation of ferrous alloys reached a stage equivalent to that of the non-ferrous alloys when these were first made by mixing the constituent metals. The date of this is uncertain, but it was first put to practical use when steel was made by melting wrought iron and charcoal.

Summarising these two stages, it may be said that alloys were first made accidentally, and then intentionally. In the first stage of intentional preparation they were made by mixing ores or by carburising iron. The procedure required to give the desired results was known, but the way in which it impressed itself on the metal was not. Later they were made intentionally by mixing the constituent metals, but the alloys made were similar to those previously produced by mixing ores, and these were in turn similar to those made accidentally in the early days of metallurgy.

(3) The third stage of development was reached when it was realised that remarkable changes in properties might be obtained by adding one metal to another in various amounts, and conscious experiment began in this way. Faraday was one of the first to study the question of alloying, and since the publication of his "Alloys of Steel" in 1821 many notable investigators have taken a hand in exploring their possibilities. The results of their labours are well known.

(4) So long as the discovery of useful alloys depended on someone striking the right composition and treatment by luck, or by a merely systematic exploration of the effect of different additions, progress was bound to be slow. The fourth stage began when the scientific study of metals had led to knowledge that enabled an understanding to be gained of the precise effect of one metal on another, the response of the resulting alloy to various treatments and the relations between its properties under different conditions and its "nature" as represented by the characteristics impressed on it by its particular composition and treatment. There is a tremendous amount of knowledge

behind the production of modern alloys. Some of this was acquired by systematic but empirical experiments, and some by scientific and quasi-scientific research, but all of it is required by the metallurgist of to-day. Looking back over the past sixty years it may be concluded that most of the outstanding developments in the field of alloys have arisen from chance, or as the outcome of experiments designed to discover whatever should happen to emerge from a study of the effect of certain variables. But as we approach nearer to the present time these experiments are seen to be guided to an increasing extent by a scientific knowledge of the phenomena involved. To-day we have reached a position in which progress definitely depends on this knowledge, and it is possible to predict to some extent the effect of a particular variation in composition and treatment.

The Study of Alloys.

Although many carefully planned and accurately executed investigations have been performed on alloys, the subject as a whole cannot be said to have been systematically studied. This is no reflection on those who have taken part in this study, for it could not, under any circumstances, have followed a preordained programme. To begin such a systematic study pure metals would be required in the first place. Then from these, binary, ternary and more complex alloys would have to be made and studied with full knowledge of the effects of casting conditions, working, thermal treatment, &c., &c. Actually alloys have been made and studied by using impure metals and in ignorance of some of the effects of casting conditions, heat and mechanical treatment. While the study of these has been going on other investigations have been pursued in order to discover how to eliminate impurities so that in the future purer alloys may be made and studied. Then from other investigations experience has been gained that has increased our knowledge about casting, working, thermal treatment and methods used in studying properties. This has been utilised in later investigations either on the same or different alloys. From time to time phenomena have been discovered which have caused an intensive application of research on particular lines, and it has been shown that work previously done in ignorance of these phenomena cannot be regarded as reliable. Considered as a whole, the study of alloys has followed a very devious route, but it has always proceeded in the same general direction, *viz.*, towards a fuller comprehension of the subject and an ability to produce a greater variety of useful and reliable alloys.

At the present time our knowledge is founded on what may be described as the characteristic nature of each individual

alloy in the condition in which it will be used. To this we relate its properties on the one hand and its previous treatment on the other. This nature is determined first of all by its composition. What are the properties of the basis metal or metals ? What are the effects of the subsidiary elements present as impurities or added by design ? Next comes the question of constitution. What sort of crystals are formed by the atoms of the elements present ? Are all the added elements in solid solution in the basis metal, and what effect do they have on its properties ? Are other constituents formed, if so of what kind are they, and what are their properties ? A third important factor is structure, *i.e.*, the arrangement of the crystals of the constituents in the solid alloy, and the fourth is condition, in which may be included the effects of cold-working, inclusions, forging defects, quenching cracks, and casting defects, such as blowholes, contraction cavities, hot-tears, &c.

The characteristic nature of the alloy as it goes into service is the basis of our study. We consider its previous treatment and its behaviour in use in relation to this, and thereby achieve a more accurate correlation between treatment and properties than would be possible if these had to be directly connected. When we know that a certain result may be obtained by a particular sequence of treatments we utilise this knowledge, but we are not satisfied until we know why this sequence gives that particular result. We are then in a position to modify this treatment so as to secure even better results, and furthermore we can often produce other alloys that will be improved by similar treatments.

The Composition of Alloys.

The study of alloys would be greatly simplified if it were possible to consider separately each of the factors that constitute its nature in relation to each stage in its treatment and each of its properties. Actually, however, nature, treatment and properties are so intimately connected that they must be considered together. Thus, although various headings may be selected to facilitate description, it is impossible to adhere strictly to this plan.

When composition is considered alone without regard to treatment, its importance is seen to vary greatly with the properties we have in mind. In the case of electrical conductivity, composition is all-important, and in preparing conductivity copper or aluminium the highest attainable purity is sought. Where it is technically impossible to eliminate all the impurities, and there is some choice as to which impurity should be left, constitution is important, because elements that do not enter

into solid solution have less effect in decreasing the conductivity than those that do. Thus, in the manufacture of high-conductivity copper the object is to eliminate other impurities by means of oxygen while leaving as little of this element as possible in the metal. If mechanical strength has to be taken into account in addition to conductivity, other aspects of the composition become important, and so does treatment. Considerable improvement in strength may be effected by cold-working without serious diminution of the conductivity of copper or aluminium, but when further increase in strength is necessary recourse must be had to some other element that raises the strength as much as possible while decreasing the conductivity to a minimum extent. Thus silicon or cadmium is added to copper to increase its strength in the cold-worked condition, and silicon, magnesium, and manganese are added to aluminium to increase its strength in the heat-treated condition.

For magnetic properties also composition is a most important factor, but treatment as affecting condition and constitution must also be considered. When high magnetic permeability is required selection is restricted to iron in the purest condition available, an iron alloy containing about 4 per cent. of silicon, and iron-nickel alloys containing about 50 or 70 per cent. of nickel. The permeability of all these metals is best when they are free from the effects of cold-working, and when they have been given the correct heat treatment, which consists of annealing the first two and of cooling the iron-nickel alloys at a controlled rate. Despite the effect of treatment, however, the composition is the controlling factor. When high remanent magnetism and high coercive force are required quite different alloys are used, and treatment becomes of even greater importance. The properties of the original carbon magnet steels depend just as much on the fact that they are quenched so as to retain them in the martensitic condition as on their high carbon content. Similarly, with the tungsten, chromium and cobalt steels subsequently introduced, heat treatment is important because of its effect on constitution, and although treatment is not so essential in developing the properties of the newer iron-nickel-aluminium magnet alloys it has, nevertheless, an important influence.

Chemical properties as exhibited by resistance to electrochemical corrosion and direct oxidation also depend primarily on composition. These influence many uses of metals, for whenever a metal is employed without a surface coating of some other metal, some compound, paint or enamel, it may be said to be thus employed because it resists satisfactorily the conditions to which it is exposed. The environments in which metals are used are very varied and a large number of them may be said to give satisfactory service in one way or another. The metals, however,

in which resistance to oxidation and corrosion are important properties are in general those that are used where others would fail. Some of the metals used in this way are pure metals, *e.g.*, lead, copper, nickel or aluminium, while others are alloys that owe their high corrosion resistance to the presence of certain elements.

Although numerous metals are used under conditions where some resistance to corrosion is required, the number of alloys that are specifically employed because of this property is not large. The basis metals of these alloys are iron, copper and nickel and the added elements are nickel, chromium, aluminium, silicon and tin. As these owe their resistance to corrosion to their capacity to form continuous adherent protective films, and confer this property on the metals to which they are added, their effect depends on their form of occurrence. The second metal must always be held in solid solution by the first. The heat- and corrosion-resisting non-ferrous alloys, *e.g.*, aluminium-bronze, aluminium-brass, nickel-copper alloys, nickel-chromium alloys and nickel-chromium-iron alloys are all solid solutions, while in ferrous alloys it is only that proportion of the protective element that is dissolved in the iron that is effective.

As chromium and iron form a continuous series of solid solutions, all the chromium would be available to protect the iron if no carbon was present. But when it is present, carbides of high chromium content are formed, and the corrosion resistance of the alloy is appreciably decreased if these are permitted to separate from solution. Thus constitution has a pronounced effect on the resistance of such steels, and must be carefully controlled. There are four general types of these steels—the pearlitic, martensitic, austenitic and ferritic. Of these the first, which is represented by stainless iron, may be regarded as an attempt to combine a fairly high resistance to corrosion with properties similar to those of high tensile structural steels. It may be used in the annealed, normalised, or quenched and tempered condition, and although the carbon, and therefore some of the chromium, is not retained in solid solution in some of the conditions of its use, sufficient chromium remains dissolved to impart a moderately high resistance to corrosion. In the martensitic type both carbon and chromium are retained in solution by heating to a temperature sufficiently high to dissolve the carbide, quenching as rapidly as possible, and tempering at a temperature below that at which carbide begins to form. If the quenching temperature is lowered, the rate of cooling decreased, or the tempering temperature raised, some chromium carbide is formed, less chromium remains to protect the iron, and the corrosion resistance is diminished.

The other two types of stainless steel are conspicuously

different from steels in general in that they do not undergo the ordinary reversible changes on heating and cooling, and do not respond to treatments like normalising, hardening and tempering. Austenitic steels were used before austenitic stainless steel was developed. Thus Hadfield's manganese steel proved invaluable for numerous purposes, because of the toughness of the austenite retained by quenching, and its tendency to transform to hard martensite on any surface subjected to wear and abrasion. Austenitic nickel steel was used because of its non-magnetic and corrosion-resisting properties. Nevertheless, the introduction of the austenitic nickel-chromium steels represents a new development in steel metallurgy, because of their high resistance to corrosion, suitability for hot- and cold-working, and insusceptibility to heat treatment in the usual sense. The ferritic stainless steels were the first steels of this type to be used.

The austenitic stainless steels illustrate some interesting aspects of the relations between composition, treatment, constitution and properties. Nickel is one of the elements that increase the range of stability of austenite, and about 28 per cent. is required to retain this constituent down to atmospheric temperatures. Chromium, however, is one of the elements that decrease the range of stability of austenite, and in the absence of carbon and nickel, no austenite is formed in iron-chromium alloys containing more than 14 per cent. of chromium. Yet when this element is added along with nickel it supplements its effect in retaining austenite down to atmospheric temperatures, and the best-known types of such steels contain chromium and nickel in the proportions 18/8, 15/11 and 20/7. The constitutional effect of chromium in these cases does not depend on its influence on the relations between γ- and α-iron under equilibrium conditions. It rests on its action in retarding transformations. An alloy containing 18 per cent. of chromium, 8 per cent. of nickel and 74 per cent. of iron solidifies as a mixture of ferrite and austenite. During cooling the ferrite changes to austenite above 1,300° C. in the same way that δ- changes to γ-iron in iron-carbon alloys. Under equilibrium conditions ferrite should begin to re-form at 850° C. and continue to below 300° C., when the alloy would consist mainly of this constituent. But at ordinary rates of cooling from 900° to 500° C., ferrite does not form at all, and the sluggishness of the alloy prevents it from forming at lower temperatures. Thus, although chromium decreases the range of stability of austenite under equilibrium conditions, in nickel-chromium steels of suitable nickel content it promotes the retention of austenite at atmospheric temperature by inhibiting the changes that should take place on cooling below 850° C.

The solubility of carbon in the nickel-chromium austenite of stainless steels is very small. According to Aborn and Bain

it decreases from 0·4 per cent. at 1,200° C. to 0·03 per cent. at 800° C., and becomes less than this at lower temperatures. The actual carbon content of these steels is generally below 0·1 per cent., but it is never below 0·03 per cent., and consequently, under equilibrium conditions, a carbide phase should be present below 800° C. Under ordinary conditions of cooling, however, the formation of carbide in the range 800°–400° C. is prevented, and it cannot take place below this temperature. Thus the carbon is retained in solid solution and assists in stabilising the austenite. But in operations that involve heating at temperatures above 450° C., diffusion of carbon can proceed at an appreciable rate, and any carbon in excess may separate from solution and form carbide. This contains a considerable amount of chromium, and as the rate of its diffusion is much slower than that of carbon, the carbide is formed from chromium drawn from the vicinity of the crystal boundaries. The chromium content is thus decreased, and corrosion is liable to occur there. It is on this that the intergranular corrosion of stainless steels depends. The technique of controlling or preventing it has since been developed.

It is evident from the foregoing that the corrosion resistance of stainless steels depends (1) on the presence of chromium, (2) on this element being dissolved in the iron, and (3) on the presence of a minimum amount of carbide. Their mechanical properties depend, however, on their constitution rather than their composition, and pearlitic, martensitic, austenitic and ferritic chromium or nickel-chromium steels resemble other steels of similar constitution more than they resemble each other.

Constitution and Structure.

Equilibrium Diagrams.

Whereas the nature of the electrical, magnetic, or chemical properties required practically determines the composition of the alloy to be used, when mechanical properties only have to be considered there is usually a choice of several alloys which will give the required results.

The study of the constitution and structure of alloys is based on their equilibrium diagrams, and, neglecting changes in the solid state, most of the diagrams that apply to the useful ranges of composition of industrial binary alloys may be classified as follows :—

(1) Each metal is soluble in the other to a limited extent when solid, and alloys of intermediate composition consist of a mixture of these two solid solutions. Examples of this type are the lead-antimony, lead-tin and nickel-chromium systems.

The aluminium-silicon system must also be included in this class, although there is no solid solubility of aluminium in silicon.

(2) The two metals are soluble in each other in all proportions when solid. The copper-nickel, iron-chromium and iron-vanadium alloys are examples of this type, but the iron-nickel, iron-cobalt and iron-manganese alloys may also be included, although the crystal structure of the solid solution changes with the composition. The two face-centred cubic metals copper and nickel form a continuous series of solid solutions with face-centred cubic lattices. The body-centred metals chromium and vanadium form a continuous series of solid solutions with body-centred iron, but when the face-centred metals nickel and cobalt are alloyed with iron, solid solutions with a body-centred lattice are formed at the iron end, while throughout the rest of the system face-centred solid solutions are produced. In the iron-manganese system, however, in addition to the body-centred solid solution formed at the iron end, and the face-centred solid solution at higher manganese contents, there is a third solid solution formed when the manganese exceeds 70 per cent., *viz.*, one based on the tetragonal lattice of γ-manganese. In these systems of alloys between iron and nickel, cobalt and manganese, respectively, solid solutions based on α-iron, γ-iron, and the other metal occur, but as the lattices of nickel and cobalt are the same as that of γ-iron there are only two different solid solutions, whereas owing to the difference between γ-iron and γ-manganese there are three different constituents in that system.

(3) At the useful end of the system the added element is soluble to some extent in the basis metal, and when this limit is exceeded a eutectic between the solid solution and an intermediate constituent appears. Examples of this type are the alloys of iron with carbon, molybdenum, tungsten and silicon and those of aluminium with copper, iron, manganese and magnesium.

(4) A series of intermediate constituents is formed as in the alloys of copper with aluminium, zinc, tin and silicon or in those of iron with aluminium.

Constituents of Alloys.

When one solid metal dissolves another a primary solid solution is formed, whose characteristic feature is that the atoms of the solute metal are incorporated in the lattice of the solvent metal. Two different types are recognised. Most primary solid solutions are of the substitutional type, *i.e.*, atoms of the solute are substituted for those of the solvent metal. Thus in the primary solid solutions formed by copper and nickel, nickel atoms are substituted for copper atoms in the copper lattice,

and as the nickel content increases the proportion of copper atoms in the lattice decreases until it consists entirely of nickel atoms. A few primary solid solutions are of the interstitial type in which the atoms of the solute take up positions in the interstices of the solvent lattice. The best-known example of this type is the solid solution of carbon in γ-iron, but it appears that interstitial primary solid solutions are generally formed when transition elements like titanium, vanadium, chromium, manganese, or iron dissolve elements with small atoms like hydrogen, carbon and nitrogen.

In systems of the first and second types mentioned above, only primary solid solutions are formed, but in those of the third and fourth types intermediate constituents also occur. The principal characteristic of the latter is that their crystal structure is different from that of either of the metals composing them. What may be described as the basic lattices of these constituents contain the two kinds of atoms in definite proportions, but the composition of a given constituent may vary by the substitution of atoms of one kind for those of the other. Thus the β constituent in copper-zinc alloys is based on a lattice containing an equal proportion of copper and zinc atoms, but its composition may vary by the substitution of copper for zinc or zinc for copper atoms.

In the numerous alloy systems that have been studied, a very large number of intermediate constituents have been recognised. In general their basic lattice contains the two metals in definite proportions, which can be represented by a formula. Metallurgists have always divided these constituents into two classes, namely, solid solutions and intermetallic compounds, and Hume-Rothery, in order to distinguish solid solutions of this type from primary solid solutions, has proposed to call them secondary solid solutions. It is, however, difficult to decide whether there is a difference in kind or only in degree between intermetallic compounds and secondary solid solutions. The intermediate constituents may be divided into two classes, in one of which we may place those that have crystal structures and other properties similar to the pure metals and a moderately wide composition range of stability, while in the other class we may place those that have crystal structures and other properties different from pure metals and a narrow range of stability. We may call the former secondary solid solutions and the latter intermetallic compounds, but we cannot be sure that the difference implied by these terms is a real one, and not just a division into two arbitrary groups of a gradually varying series of constituents. At the present time it is possible either to regard all the intermediate constituents as compounds because they may be represented by a formula, or to regard none of them as compounds

because the existence of different atomic linkages in different metallic constituents has not yet been proved, or to classify them into groups on the basis of composition range of stability, mechanical properties, melting point and the relations between their crystal structure and that of the pure metals.

The original classification of alloy constituents is further complicated by the knowledge that has been acquired in the study of the distribution of different kinds of atoms in crystal lattices. In most of the intermediate constituents the two kinds of atoms are disposed in an orderly manner on a common space lattice, so that if all the atoms of either kind could be removed without displacing the others these would still be arranged in a regular pattern. In most primary solid solutions the two kinds of atoms are arranged in a disorderly manner on the common space lattice, so that if all the atoms of either kind could be removed without displacing the others, these would not form a regular pattern in space. In certain intermediate constituents, however, *e.g.*, the β phase in the copper-tin system, there is no order in the disposition of the two kinds of atoms, in certain others, *e.g.*, the β phase in the copper-zinc system, a change from a disordered to an ordered arrangement takes place, and the same kind of change also takes place in several primary solid solutions, *e.g.*, iron-aluminium, copper-gold and probably iron-nickel, and iron-vanadium. As the development of a perfectly ordered arrangement of two kinds of atoms in a given space lattice requires their presence in definite proportions, these symmetrical lattices formed from primary solid solutions can be represented by formulæ, *e.g.*, Fe_3Al, FeAl, Cu_3Au and FeV.

Following on the concepts originally advanced by Hume-Rothery, it has been shown that the formation of many intermediate constituents requires a certain ratio between the number of atoms and the number of valency electrons. Thus in the six alloy systems containing copper, silver and gold on the one hand, and zinc and cadmium on the other, the basic lattices of the β phases have formulæ of the form CuZn, and the ratio of valency electrons is 3 to 2, while the γ phases have formulæ of the form Cu_5Zn_8, and the ratio of valency electrons to atoms is 21 to 13. In the copper-tin system the formula of the β phase is Cu_5Sn, which gives a ratio of 3 electrons to 2 atoms, while that of the δ phase is $Cu_{31}Sn_8$, which gives a ratio of 21 electrons to 13 atoms. The same rule applies to the β and δ constituents in the copper-aluminium system, which have the formulæ Cu_3Al and Cu_9Al_4. The phases based on the compositions NiAl, CoAl, MnAl and FeAl, all have the same space lattice as CuZn. Aluminium has 3 valency electrons, and therefore if the ratio of 3 electrons to 2 atoms applies to these constituents it must

be assumed that the transition elements do not contribute any valency electrons to the crystal structure. If the valency of such elements in phases of this kind can be assumed to be zero, the compositions at which phases with the γ brass structure should appear may be calculated. As this contains valency electrons and atoms in the ratio of 21 to 13, it should appear in phases containing the compositions Fe_5Zn_{21}, Co_5Zn_{21}, Ni_5Zn_{21}, &c. Westgren has shown that this expectation is realised.

It is evident from the above that there is a general similarity in crystal structure between constituents that differ considerably in their properties and conditions of formation, *e.g.*, FeAl, Cu_3Al and NiAl, and at the present time it is difficult to reconcile the classification of constituents on a basis of crystal structure with one on the basis of properties and conditions of formation. It is wisest at present to describe as intermediate constituents all those phases that are not primary solid solutions.

Structure.

Cast solid-solution alloys have a well-known cored structure, but the extent to which the composition varies within the individual crystal depends on the distance between the liquidus and solidus. Thus coring is pronounced in copper-nickel alloys near the middle of the system, and in α brass, but is less pronounced in copper-aluminium alloys. Working and annealing eliminate the cored structure, and a system of uniform polyhedral crystals is produced. After this treatment the mechanical properties depend on the composition of the solid solution and the size of the crystals. Cold-working deforms the crystals and increases the strength of the alloy. In many alloys this may be further increased by low-temperature annealing after working, *e.g.*, in steel and nickel-copper alloys, but if the temperature is high enough the effect of cold-working disappears, and the mechanical properties then depend on the crystal size established in the annealed metal.

In systems of the second type mentioned above only solid-solution crystals are formed. In those of the first and third types a eutectic appears when the limit of solubility of the added element in the basis metal is exceeded. This forms a matrix in which primary crystals of the solid solution are embedded, and if its properties are very different from those of the solid solution there is a marked change in them when it appears. This is most clearly shown in iron-carbon alloys, for whereas those that contain no eutectic can be forged with ease, those containing eutectic can only be forged with great difficulty, if at all. The same applies to aluminium-copper alloys, which are unsuitable for working when the copper exceeds 5 per cent. In

both systems the sudden change in working properties that accompanies the appearance of the eutectic is due to the brittle nature of the new constituent that occurs in it. It is also due, however, to its distribution, and in aluminium-silicon alloys in which silicon occurs in the eutectic, the working properties are not seriously affected, because the silicon is present as discontinuous particles in a soft matrix.

When an alloy consists of a fairly ductile constituent in a matrix of a brittle eutectic, working tends to break up the brittle and establish continuity of the ductile constituent, and if this can be done without fracturing the metal, subsequent working may be carried out with comparative ease. Thus iron-carbon alloys containing the austenite-cementite eutectic may be worked to a certain extent if the amount of the eutectic is not too great and sufficient care is exercised in the early stages. Similarly, aluminium-copper alloys containing up to 10 per cent. of copper have been hot-rolled experimentally, and finally high-speed steel, which solidifies as crystals of austenite surrounded by a net-work of austenite-carbide eutectic, is forgeable if care is taken in the early stages when the network is being broken up.

In systems of the fourth type various changes occur in the solid state, and consequently the structures that exist at atmospheric temperature are different from those formed on solidification. Alloys of copper with silicon, or of iron with aluminium, in which the proportions of silicon or aluminium exceed the amount soluble in the primary α solid solution are not used. The useful alloys of copper and tin solidify as α or as $\alpha + \beta$, while those of copper with zinc or aluminium solidify as α, $\alpha + \beta$ or β. In the copper-zinc and copper-tin systems the β formed at solidification does not occur in a eutectic with α, whereas in the copper-aluminium system such a eutectic is formed. In the copper-zinc and copper-aluminium systems alloys that solidify as $\alpha + \beta$ change to α during subsequent cooling. In copper-aluminium and copper-tin alloys β undergoes a eutectoid change. Thus at atmospheric temperatures, the copper-zinc alloys consist of α, $\alpha + \beta$ or β, and the α in the $\alpha + \beta$ alloys is formed from β by a change in the solid. The copper-tin alloys consist of α or $\alpha + (\alpha + \delta)$ eutectoid, the latter being formed from β produced at solidification. The copper-aluminium alloys consist of α or $\alpha + (\alpha + \delta)$ eutectoid, and when a structure of the latter type exists it is all formed from β.

Transformations in Solid Alloys.

One of the most recently discovered changes is that which involves rearrangement of the atoms in a solid solution. The transformation in β brass between 453° C. and 470° C. which

has been the subject of so much controversy is now considered to be due to such a rearrangement, as a result of which an ordered distribution of two kinds of atoms is produced. Thus above the transformation range copper and zinc atoms are distributed at random among the lattice points of the body-centred lattice, while below it each kind of atom occupies all the lattice points on one of the interpenetrating simple-cubic lattices of which the body-centred lattice is made up.

Similar changes from disordered to ordered distribution occur in copper-gold and iron-aluminium alloys. Copper and gold form a continuous series of primary solid solutions, and above 420° C. the two kinds of atoms are distributed at random among the lattice points of the face-centred cubic lattice. With moderately rapid cooling this random distribution persists down to atmospheric temperature, but during slow cooling or subsequent reheating in the appropriate range of temperature, ordered structures result. One of the constituents thus produced contains 75 atomic per cent. of copper and 25 atomic per cent. of gold, and may therefore be represented by the formula Cu_3Au. The other contains equal atomic proportions of gold and copper, and may be represented by the formula CuAu. By the substitution of gold for copper or copper for gold atoms the β constituent (Cu_3Au) may vary in composition from 17·5 to 35·5 atomic per cent. of gold, according to Haughton and Payne, while the δ constituent (CuAu) may vary in composition from 36·5 to 71 per cent. of gold. In Cu_3Au the gold atoms occupy the corner positions in the face-centred cubic lattice and the copper atoms the face-centred positions. In CuAu a face-centred tetragonal lattice is formed with gold atoms in the corner positions and in two of the face-centred positions, while the copper atoms occupy the remaining four face-centred positions.

In copper-gold alloys cooled rapidly from above 500° C. the two kinds of atoms are distributed at random on a face-centred cubic lattice, and the properties vary with composition in the manner characteristic of primary solid solutions. The electrical resistance and hardness rise to a maximum at 55 atomic per cent. of gold and are related to composition by smooth curves. In slowly-cooled alloys, when β and δ are formed, several discontinuities appear in the curves connecting hardness and resistance with composition. At the exact compositions Cu_3Au and CuAu sharp minima occur on them. On each side of these compositions the resistance rises rapidly, while the hardness rises rapidly on each side of the composition CuAu. In an alloy containing 75 atoms per cent. of copper the Brinell hardness is 60 when quenched and 42 when slowly cooled, and in one containing 50 atomic per cent. of copper it is 115 when quenched and 100 when slowly cooled. In alloys containing 45 and 55

atomic per cent. of copper, respectively, the hardness is about 95 when quenched and 188 when slowly cooled. These alloys may therefore be obtained in a soft condition by quenching and may be hardened by reheating at a suitable temperature.

Similar changes occur in iron-aluminium alloys. Up to 33 per cent. of aluminium these consist of primary solid solutions in body-centred α-iron. As far as 9·9 per cent. the two kinds of atoms are distributed at random among the lattice points of the body-centred lattice. Then, as shown by Bradley and Jay, a symmetrical arrangement begins to form in slowly-cooled alloys. At 13·9 per cent. (25 atomic per cent.) all the aluminium atoms are situated on one of the four face-centred cubic lattices of which the body-centred cubic lattice may be said to be composed. This gives the superlattice Fe_3Al. Above this the atoms of aluminium begin to fill the lattice points on another of the four interpenetrating face-centred lattices. At 32·6 per cent. (50 atomic per cent.) this process is completed, and the superlattice FeAl results. The changes from the disordered to the ordered distribution of atoms in alloys containing between 10 and 33 per cent. of aluminium are influenced by the rate of cooling, and the effect of this on the physical properties has been studied by Sykes and Morgan. With the exception of electrical resistivity, the effects observed were small, and it therefore appears that the formation of FeAl or Fe_3Al is not accompanied by hardness changes like those caused by the formation of Cu_3Au and CuAu.

Changes of solid solubility are utilised to produce alloys of considerable practical importance. These occur in the systems of types (1) and (3), and their importance depends on the fact that they are influenced by the rate of cooling. In certain alloy steels of hypereutectoid composition, quenching from a high temperature is utilised to retain in solution as much carbide as possible, *e.g.*, in high-speed and austenitic manganese steels.

The changes of solid solubility of copper and Mg_2Si in aluminium are utilised in the heat treatment of light aluminium alloys. At the eutectic temperature (548° C.) aluminium dissolves 5·65 per cent. of copper. The solubility decreases rapidly as the temperature falls and is only 0·5 per cent. at 200° C. By quenching, the formation of $CuAl_2$ may be prevented, and thus, depending on the quenching temperature, alloys containing up to 5·5 per cent. of copper may be retained at atmospheric temperatures as solid solutions. The same applies to those containing Mg_2Si. After quenching, pure aluminium-copper alloys and alloys of aluminium with copper and Mg_2Si undergo a change at atmospheric temperatures which results in an increase of strength and hardness. This is known as age-hardening. On heating, this proceeds more rapidly and is known as accelerated age-hardening.

If, however, the time of heating is sufficiently prolonged or the temperature sufficiently high, the hardness reaches a maximum and then begins to decrease. In general, therefore, the change under consideration may be said to be accompanied first by an increase and then by a decrease in hardness.

In explanation of these changes, Merica, Waltenberg and Scott advanced the "critical dispersion" hypothesis, which attributed the increase in hardness to the precipitation of $CuAl_2$ or Mg_2Si in the form of submicroscopic particles, and the subsequent softening to their coalescence. This hypothesis was widely, but not universally, accepted, and more recent work has shown that the change is more complicated than was originally supposed. As a result of this hypothesis the terms precipitation and dispersion hardening came into use, and temper hardening is also employed in the case of alloys like copper-beryllium, copper-aluminium-silicon, copper-aluminium-nickel, iron-molybdenum, iron-tungsten, &c., which require to be heated to promote the changes in question.

The nature of the change that occurs when an unstable solid solution decomposes at atmospheric temperatures or during heating is by no means easy to discover. The most reliable criterion of the condition of the alloy is the lattice parameter of the solid solution. So long as this remains expanded or contracted by the presence of the solute atoms it is a solid solution. When it returns to the dimensions characteristic of the pure solvent metal precipitation has occurred. Intermediate stages involving a concentration of the dissolved constituent before precipitation should be marked by changes in the appearance of the lines on the X-ray spectrogram. In the aluminium alloys that harden at atmospheric temperatures the increase in hardness is not accompanied by a change in lattice parameter. Thus hardening may take place without precipitation. When the hardening is accelerated by heating it is accompanied by precipitation. But it remains to be seen whether it is due to this precipitation. It is not impossible that, under conditions which permit a certain amount of precipitation, the increase in hardness is caused by some change in the arrangement of the atoms still in solid solution.

The changes that remain to be considered are those that involve the formation of one phase from another, *e.g.*, ferrite from austenite, α from β brass, or the decomposition of a solid solution into two other constituents, *e.g.*, the eutectoid changes in steel, copper-aluminium alloys, &c. The transformation from austenite to ferrite and pearlite is the most important of all changes in solid alloys. The heat treatment of steel is based on it, and many of the properties of alloy steels are due to the effect of the alloying elements on the course of this change.

It has been the subject of innumerable investigations and yet important discoveries are still being made, as exemplified by recent work on the effect of austenite grain-size on the hardenability and the mechanical properties of a steel of a given composition.

The eutectoid change in certain copper-aluminium alloys is of less practical importance, but it is, nevertheless, of great interest because of its similarity to the change in steel. When a steel of eutectoid composition is quenched the formation of pearlite is suppressed, but the austenite is not retained unchanged at atmospheric temperatures. During rapid cooling the space lattice of the iron changes from the face-centred to the body-centred form with the carbon held in solid solution. Owing to the presence of the carbon the space lattice of martensite is different from that of ferrite, and the unit cell is tetragonal instead of cubic, but the difference is one of degree and not of kind, for it increases progressively with carbon content. Similar results are obtained with copper-aluminium alloys. When an alloy of eutectoid composition is quenched from the β range the eutectoid transformation is suppressed, but β is not retained unchanged at atmospheric temperature. During rapid cooling the lattice changes from body-centred β to face-centred α, but owing to the retention in solid solution of more aluminium than is normally soluble the α lattice is distorted.

The structural aspects of the formation of the eutectoid in steel and aluminium bronze are very similar, and so are the results of accelerated cooling. But the effect of rapid cooling on the mechanical properties is quite different, for whereas steel of such composition is hardened by quenching and softened by tempering, aluminium bronze is softened by quenching and hardened by tempering.

To sum up, composition is the first factor to be considered in connection with the properties of an alloy. All properties depend on this to a greater or less extent, but other factors—constitution, structure and condition—are also important. The composition is fixed when the alloy is cast, while the other factors are influenced by the casting technique, and the heat and mechanical treatment of the solid metal. Most of the alloys used in the cast condition contain a eutectic, *e.g.*, the cast irons, aluminium-coppers, and aluminium-silicons. Bronze contains a eutectoid, while brass consists of solid solutions. Most of the alloys used in the worked condition solidify as solid solutions, *e.g.*, steel, brass, copper-nickel, and the heat-treatable alloys of aluminium. Finally, most of the alloys subjected to heat treatment solidify as solid solutions and undergo subsequent changes in the solid, *e.g.*, steel and the heat-treatable light alloys.

Heat treatment consists of controlled heating and cooling

operations designed to modify the properties of an alloy by promoting or preventing constitutional and structural changes. But these are also influenced by the presence of elements other than those required, which have to be reckoned with. Steel is the outstanding example of an alloy in which the mechanical properties depend on constitution and structure, and the control of these by heating and cooling and by the addition of other elements. The heat-treatable alloys of aluminium fall into the same category as do the more recently developed heat-treatable alloys of copper and nickel. Certain elements facilitate the retention of the soft condition by quenching, others promote the necessary precipitation hardening during the cooling of a chill casting or a hot stamping, others accelerate or retard precipitation hardening at atmospheric or elevated temperatures, while others may be used to raise the recrystallisation temperature so that the hardening due to cold-working and precipitation may be simultaneously utilised.

Votes of Thanks.

To the President for his Address.

Sir Robert Hadfield, Bt., F.R.S. (Past-President), said the very pleasant duty had fallen to him of proposing a vote of thanks to the President. He was quite sure that the members would see from the splendid Address which the President had delivered that metallurgy was a very important branch of science. It was no longer a rule-of-thumb matter, as it had been very largely in his own early days; he used to depend on the blacksmith for help, and indeed received very great help. He was glad to see that the President referred in a very admirable manner to the quasi-scientific side of the subject; it must not be forgotten that there was a technical side as well as a pure science side.

The President had given a most admirable Address on the pure science side of metallurgy, and the members were greatly indebted to him. When one thought of the importance of alloys, especially of iron, to-day, one would realise all that that implied. He believed that the output of steel to-day was something like 70 to 80 million tons per annum, and at least 10 to 12 per cent. of that steel was represented by the production of alloy steel, but the enormous importance of that 10 or 12 per cent. far exceeded what its tonnage would suggest. Many modern conveniences could not be produced except by the use of alloy steel, and the world was very greatly indebted to that pioneer of alloy steels, Michael Faraday. When one studied the remarkable alloys which he had made, and which personally he had ventured to describe in a little book, one saw how great was the debt due to that scientist for starting the early examination of alloys of iron with other elements. Whether one would ever come to a primordial element which would have no alloys he could not say, but it might be possible one day.

The President had put before the Institute a very admirable study of alloys from the pure scientific side, and the members were greatly indebted to him for his Address.

[The vote of thanks was carried unanimously by acclamation.]

The President (Sir Harold Carpenter, F.R.S.) thanked Sir Robert Hadfield very much for the kind words he had used in proposing the vote of thanks. It was a great pleasure to him that the vote of thanks should be moved by a man who had produced one of the most famous alloys that ever existed, manganese steel. He would like to add that he had been greatly assisted in the preparation of the Address by a member of his own staff, Dr. J. M. Robertson, and he desired to make public acknowledgment of that fact.

To the Institution of Civil Engineers.

The PRESIDENT'S motion, that a cordial vote of thanks be accorded to the President and Council of the Institution of Civil Engineers, who once again had put their lecture theatre at the disposal of the Institute was carried by acclamation.

To the President.

A very hearty vote of thanks to the President for his able and charming conduct of the meeting was carried by acclamation.

SYMPOSIUM ON THE WELDING OF IRON AND STEEL.

Thursday and Friday, May 2 and 3, were devoted entirely to the discussion of papers contributed to the Symposium on the Welding of Iron and Steel, which had been organised by the Institute in co-operation with the following Societies:

The British Iron and Steel Federation.
The British Steelwork Association.
The Institute of British Foundrymen.
The Institute of Marine Engineers.
The Institution of Automobile Engineers.
The Institution of Civil Engineers.
The Institution of Electrical Engineers.
The Institution of Engineers and Shipbuilders in Scotland.
The Institution of Mechanical Engineers.
The Institution of Naval Architects.
The Institution of Structural Engineers.
The Institution of Welding Engineers.
The North East Coast Institution of Engineers and Shipbuilders.
The Royal Aeronautical Society.
The South Wales Institute of Engineers.

The arrangements had been placed in the hands of an Organising Committee consisting of:

President: Sir Harold Carpenter, F.R.S. (President of the Institute).
Vice-President: Dr. H. J. Gough, F.R.S.
Members: Mr. E. C. Evans.
Dr. W. H. Hatfield, F.R.S.
Mr. James Henderson.
Dr. A. McCance.
Dr. T. Swinden.
Mr. B. Talbot.
Secretary: Mr. K. Headlam-Morley.

The papers, totalling one hundred and fifty, had been divided into five groups and sub-groups, and arrangements had been made for each group or sub-group to be presented in summary form by a rapporteur.[1]

[1] The whole of the papers, the rapporteurs' summaries, the discussions and correspondence and the Organising Committee's survey of the proceedings will be published in two bound volumes.

On Thursday, May 2, the proceedings opened at 10 A.M. under the Chairmanship of Sir HAROLD CARPENTER, F.R.S., who was supported by the Presidents of the co-operating Societies. In his opening remarks the Chairman explained how the Symposium had come into being and what was its precise object. The matter had been raised more than a year ago at a Meeting of the Metallurgy Research Board of the Department of Scientific and Industrial Research. Dr. Gough had made the original suggestion that the subject of welding was not receiving the scientific attention in Great Britain that it deserved. As a result the Department had asked the Iron and Steel Institute to make itself responsible for the holding of the Symposium. He referred to the valuable co-operation given by the fifteen other Societies, the total membership of which was something like 100,000.

One hundred and fifty papers had been submitted, including a great many from other countries. The purpose of the Symposium was to obtain the latest possible information regarding the art and practice of welding, the difficulties encountered in carrying it out and the research work in hand directed towards the solving of those difficulties; arising out of that information it should be possible to determine in what direction further research work was necessary, and it was the intention of the Organising Committee to consider the papers and discussion and then to evolve certain conclusions, so as to be in a position to advise the Government Department as to what further research should be done and should, if necessary, be assisted.

Dr. S. F. DOREY was then called upon to introduce the papers in Group 1, Sub-group (*a*) on "Present-Day Practice and Problems of Welding in the Engineering Industries: Bridge and Structural Engineering, Pressure Vessels, Railway Material, Shipbuilding," and these were then thrown open to discussion.

At the afternoon session Sir Harold Carpenter invited Professor W. M. THORNTON, O.B.E. (President of the Institution of Electrical Engineers), to take the Chair; later in the afternoon he was followed by Dr. H. J. GOUGH, F.R.S. (Vice-President of the Organising Committee). During this session the papers in Group 1, Sub-group (*b*) on "Present-Day Practice and Problems of Welding in the Engineering Industries (continued): Aeronautical, Automobile, Chain and Electrical Industries, Iron and Steel Castings and Wrought Iron," were discussed; these had been presented by Professor B. P. HAIGH.

On the morning of Friday, May 3, at Sir Harold Carpenter's invitation, Sir RICHARD REDMAYNE, K.C.B. (President of the Institution of Civil Engineers), took the Chair. During this session two groups of papers were discussed; those in Group 2 on "Welding Practice and Technique, including Welding Apparatus,"

were presented by Dr. A. McCance, while Dr. T. Swinden presented the papers in Group 3 on "The Metallurgy of Welding."

At the final session the Chair was taken by Colonel A. E. Davidson, D.S.O., A.D.C. (President of the Institution of Mechanical Engineers). The papers presented for discussion were those constituting Group 4 on "Specification, Inspection, Testing and Safety Aspects of Welding"; they were presented by Dr. H. J. Gough, F.R.S.

At the conclusion of the Meeting, Sir Harold Carpenter, F.R.S. (President of the Organising Committee), resumed the Chair. After referring to the great success of the Symposium, he proceeded to move a vote of thanks to the Institution of Civil Engineers for making available their Great Hall for the holding of the Symposium, to the Members of the Organising Committee, and particularly Dr. Gough, for their labours in making the arrangements, and to the staff of the Institute which had undertaken all the work involved in the preparation of the papers and in carrying through the details of the Meeting. He likewise wished to thank those gentlemen who had supported and assisted him by taking the Chair at the sessions, the authors of the papers and those who had prepared the group summaries, and he desired to include Dr. J. E. Holmstrom who had acted as interpreter.

Mr. F. W. Hill (President of the Institution of Welding Engineers) proposed a very hearty vote of thanks to Sir Harold Carpenter as an expression of the appreciation by the Meeting of his great services to the Symposium.

Sir Harold Carpenter responded briefly, and the proceedings then terminated.

On the eve of the Symposium, Wednesday, May 1, a Conversazione was held at the Science Museum, South Kensington, by the courtesy of the Director, Colonel E. E. B. Mackintosh, D.S.O.

At 8 p.m., Sir Harold Carpenter, F.R.S., (President of the Symposium and President of the Iron and Steel Institute), supported by the Presidents of co-operating Societies, received the guests, and at 8.30 p.m. he declared open an Exhibition of Welding which had been organised by representatives of companies engaged in the welding industry in Great Britain. In addition to the exhibits, demonstrations of welding were given, and a number of cinematograph films illustrating various aspects of the application of welding and oxygen cutting were shown in the Lecture Theatre. A programme of music was performed during the evening by the String Band of the Honourable Artillery Company, by permission of the Colonel Commandant, Colonel the Earl Fortescue, M.C.

Acknowledgments must here be made to Colonel E. E. B.

Mackintosh, D.S.O., Director of the Science Museum, for granting facilities for holding the Conversazione and the Welding Exhibition, and to the numerous companies and others who provided the exhibits and loaned the cinematograph films.

The Exhibition remained open to the public for a fortnight.

FURTHER DETERMINATIONS OF THE EXTERNAL HEAT LOSS OF BLAST-FURNACES.[1]

By D. F. MARSHALL, B.Sc., Tech., Ph.D. (Sheffield).

Summary.

The paper is a record of an experimental determination of the external heat loss from four blast-furnaces, selected to cover a wide range of rate of production, type of product and general practice. The influence on the heat loss of various factors such as the rate of drive, the life of lining, cooling winds, exposed sites, the use of bosh tuyeres and the water cooling of shafts, has been investigated and an attempt made to measure their effect on furnace operation, in terms of fuel consumed.

The results indicated that the external heat loss was largely a function of the superficial area of the furnace and was considerably lower than the estimates previously given. The relationships existing between the heat losses from the furnaces examined did not appear to be materially affected by changes in operation from furnace to furnace, or on one furnace.

In all cases the cooling water used accounted for more than 82 per cent. of the total heat loss and it seems probable that a study of this loss might result in improvements in furnace operation.

The heat losses by radiation and convection from the shaft, and by conduction through the ground, were relatively small.

An earlier investigation of the external heat loss of a blast-furnace[2] suggested that this loss was considerably smaller than had been thought probable, and was mainly in the cooling water used.

Further tests have been made to elucidate the factors governing this loss of heat. For this purpose a determination of the external heat loss of four different furnaces has been made. On one furnace two investigations have been carried out to observe the influence of varying operating conditions on the external heat loss. In choosing furnaces for examination, the size, type and general practice has been borne in mind to enable the investigation to cover as wide a range as possible.

The lines of all four furnaces examined are illustrated in Figs. 1, 2, 3 and 4. The external heat losses measured were :—(*a*) From the shaft, by radiation and convection, (*b*) from the bosh, spectacle belt and hearth, by cooling water ; and (*c*) from the hearth, by conduction through the ground. Each of these

[1] Received October 25, 1934. The research reported in this paper was carried out with the aid of a grant from the Carnegie Research Fund of the Iron and Steel Institute.

[2] D. F. Marshall, "The External Heat Loss of a Blast Furnace", *Journal of the Iron and Steel Institute*, 1933, No. I. p. 127.

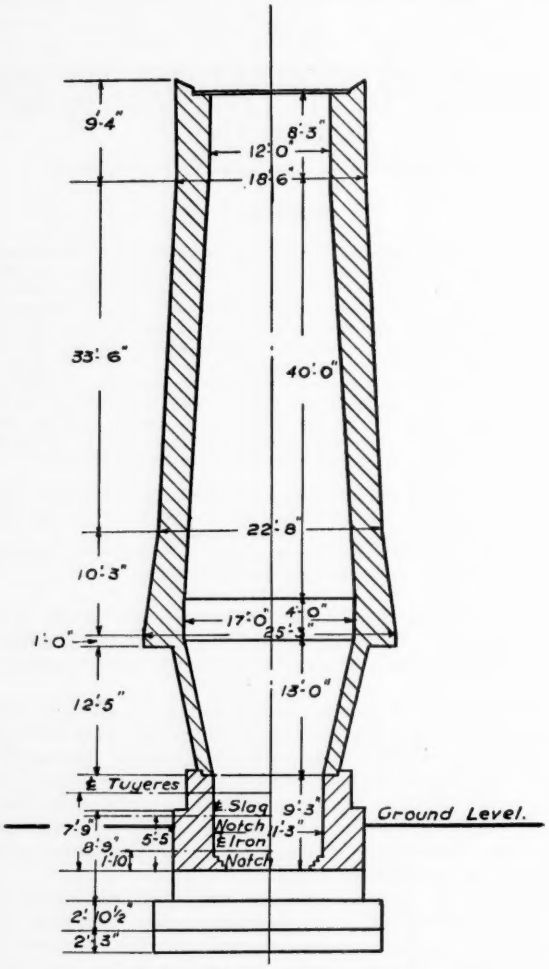

FIG. 1.—Furnace Lines, Plant *A*.

heat losses was determined separately. At one plant the heat loss in the cooling water from the tuyeres, bosh sprays, hearth cooling plates and cigar coolers on the shaft was determined separately.

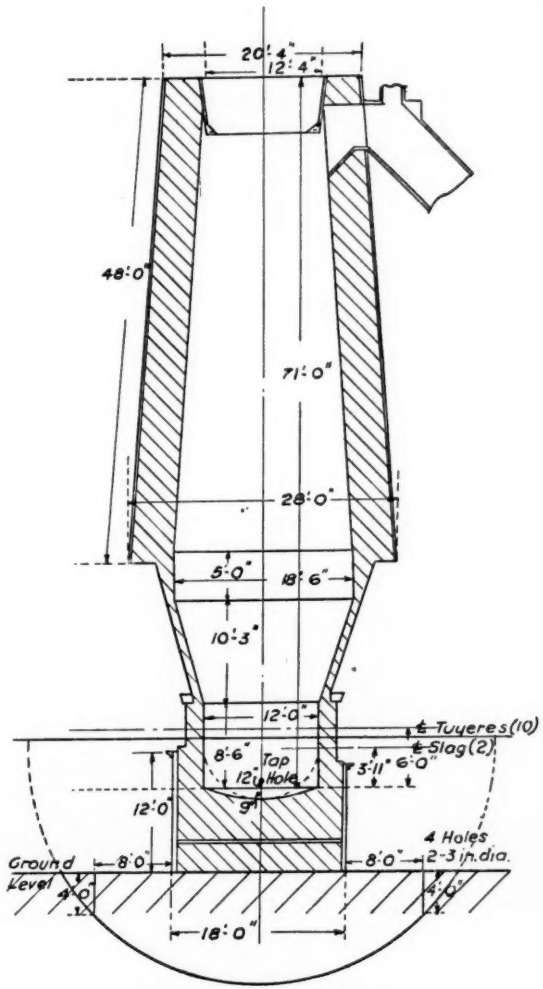

FIG. 2.—Furnace Lines, Plant *B*.

I.—HEAT LOSS FROM THE SHAFT.

The heat loss from the shaft of each furnace was determined as follows:

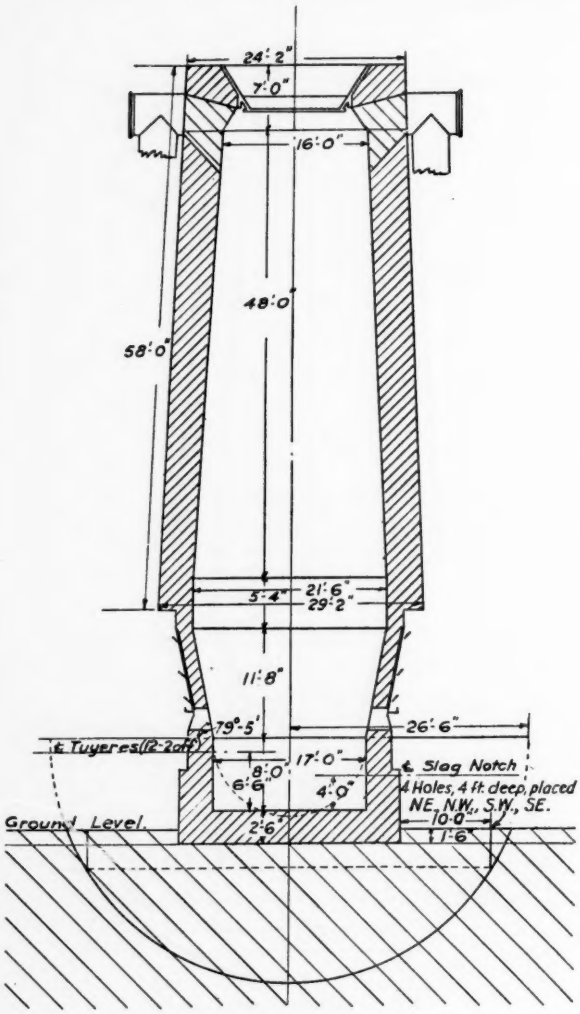

FIG. 3.—Furnace Lines, Plant *C*.

(*a*) *Shaft Temperatures.*—Each shaft was divided by horizontal bands of plates into approximately equal divisions between

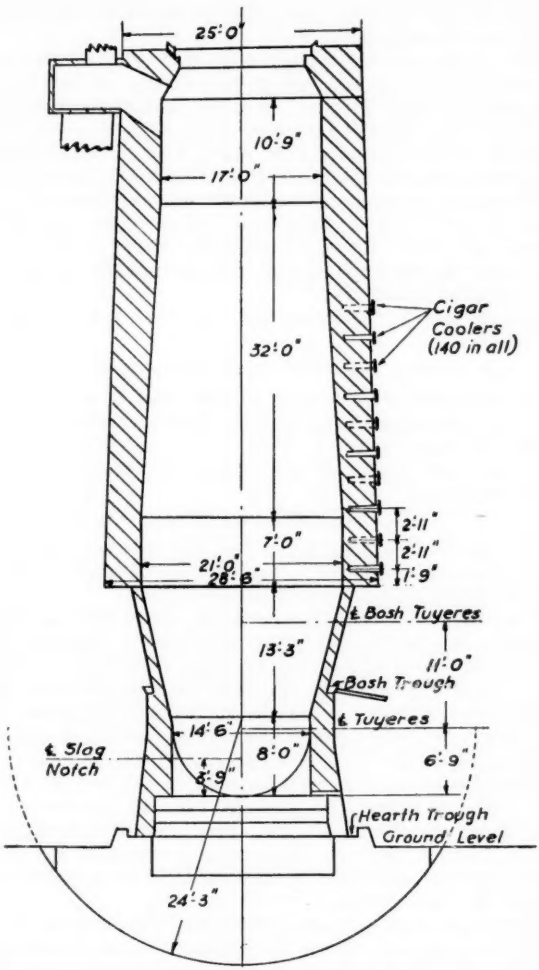

FIG. 4.—Furnace Lines, Plant *D*.

5 and 6 ft. high. These divisions were subdivided vertically into 11 sections at Plant *B*, 10 at Plant *C*, and 28 at Plant *D*. The shell temperature on each section was taken as the average of at least four readings, recorded on a Cambridge surface

pyrometer. Two or three complete temperature surveys were made for each investigation.

(*b*) *Air Temperature.*—During each survey the temperature of the surrounding air was taken periodically at the top of a neighbouring (unused) furnace, or other suitable structure.

(*c*) *Wind Velocity.*—The average wind velocities recorded for the days on which the tests were made were obtained from the meteorological stations nearest to Plants *B* and *C*, but at Plant *D* the wind velocity was recorded on a Stanley anemometer.

Table I. gives the average shell temperatures recorded on each band of plates for each plant (average of all surveys), together with the distance in feet from the middle of each plate to the bottom of the shaft.

The heat loss by radiation, H_1, has been calculated using Stefan's Law:

$$H_1 = E \times 17{\cdot}3 \times 10^{-10} (T_1^4 - T_2^4) \text{ B.th.u. per sq. ft. per hour.}$$

where E the emissivity constant $= 0{\cdot}96$, and T_1 and T_2 are the absolute temperatures of the furnace shell and the surrounding air in degrees fahrenheit.

The heat loss by forced convection, H_2, has been obtained from the expression:

$$H_2 = K\theta_1 \text{ B.th.u. per sq. ft. per hr.}$$

where θ_1 is the temperature difference between the furnace shell and the surrounding air. The value of K has been deduced from Fig. 30 of Fishenden and Saunders' work.[1]

By assuming the furnace to be a flat plate with an effective width equal to one diameter, the appropriate constant for the wind velocity recorded during each survey was derived and used in calculating H_2. In all cases, the total heat loss by radiation and convection from the shaft has been taken as the total of the values calculated separately for each band of plates.

The results are recorded in Table II. It will be seen that the wind velocities for each survey have been obtained at Plants *C* and *D*. The average wind velocity for the north-west coast deduced from the Meteorological Office Monthly Summary for 1932 was 18·2 ft. per sec. The figures recorded for the first survey at Plant *C* may therefore be considered to represent normal conditions for this district.

The average wind velocity during the three surveys at Plant *D* was 11·2 ft. per sec. Since this furnace was on a more exposed site that that at Plant *A*, where the wind velocity over an extended period was 7·9 ft. per sec., and the average yearly velocity at Plant *C* was 18·2 ft. per sec. on a site still more exposed to the wind, the average of the three surveys may be taken to represent normal conditions. The average heat losses for the three surveys

[1] "The Calculation of Heat Transmission," London, 1932.

TABLE I.—*Shaft Temperatures.*

Plant :	*A.*		*B.* (1st Test.)		*B.* (2nd Test.)		*C.*		*D.*	
Plate No.	Distance from Bottom of Shaft. Ft.	Average Temperature on Plate. °F. °C.	Distance from Bottom of Shaft. Ft.	Average Temperature on Plate. °F. °C.	Distance from Bottom of Shaft. Ft.	Average Temperature on Plate. °F. °C.	Distance from Bottom of Shaft. Ft.	Average Temperature on Plate. °F. °C.	Distance from Bottom of Shaft. Ft.	Average Temperature on Plate. °F. C °.
Top plate, 1	51·3	81·2 27·3	45·6	82·3 28	45·6	50·0 10·0	55·3	95 35·0	51	70·1 21·2
2	45·9	90·9 32·7	40·8	85·9 29·9	40·8	49·9 10·0	50·1	95 35·0	45	73·0 22·8
3	40·5	103·5 39·7	36·0	91·2 33·9	36·0	50·5 10·3	44·8	82·5 28·1	39	92·8 33·8
4	35·1	114·4 45·8	31·2	94·1 34·5	31·2	52·2 11·2	39·5	88·1 31·2	33	108·5 42·5
5	29·7	120·8 48·8	26·4	89·2 31·8	26·4	55·0 12·8	34·3	94·1 34·5	27	145·6 63·1
6	24·3	136·6 58·1	21·6	96·0 36·1	21·6	62·1 16·7	29·0	100·7 38·2	21	157·4 69·7
7	18·9	161·6 72·0	16·8	106·7 41·5	16·8	67·6 19·8	23·7	107·2 41·8	15	143·4 61·8
8	13·5	186·8 86·0	12·0	111·6 44·2	12·0	74·1 23·4	18·5	115·9 46·6	9	133·4 56·3
9	8·1	175·3 79·6	7·2	115·8 46·6	7·2	76·5 24·7	13·2	131·4 55·2	3	118·6 48·1
10	2·7	154·0 67·8	2·4	113·5 45·3	2·4	73·5 22·9	7·9	152·8 67·1		
11							2·6	161·8 72·1		
Average Air Temp. :		49·2 9·6		73·1 22·8		42·7 6·0		59·7 15·4		46·6 8·1

TABLE II.—*Heat Loss from Shaft by Radiation and Forced Convection.*

Plant.	Survey.	Wind Velocity Ft. per sec.	Area of Shaft. Sq. ft.	Heat Loss. B.th.u. per hr.			Heat Loss per sq. ft. per hr.
				(1) By Radiation.	(2) By Forced Convection.	Total	
A.	Average of three	7·9	3562	382,100	345,090	727,190	204
B. (1st test)	Average of three	5·5	3643	104,980	80,240	185,220	51
B. (2nd test)	Average of three	13·4	3643	63,310	111,350	174,660	48
C.	1	17·8	4857	308,800	536,740	845,540	174
	2	28·6	4857	269,050	711,360	980,410	202
D.	1	15·0	4537	333,420	533,220	866,640	191
	2	15·7	4537	321,910	524,550	846,460	186
	3	2·9	4537	393,710	223,820	617,530	136

at Plant *D* were 191, 186, and 136 B.th.u. per sq. ft. per hr., giving a mean value of 172 B.th.u. per sq. ft. per hr.

Ia.—Heat Loss From Spectacle Belt.

The spectacle belt of each furnace consisted of a cylindrical zone including the cast-iron straps holding the tuyeres in position, the water-cooling blocks round the tuyeres and any refractory material exposed to the atmosphere, between the top of the hearth and the bottom of the bosh. During each test, about 50 readings were taken on the various surfaces with the surface pyrometer and averaged. The temperature of the surrounding air during the corresponding period was also noted.

The heat loss by radiation was calculated, using the same formula as for the shaft losses, and since this zone was surrounded by a belt of relatively stationary air, still-air conditions may be assumed.

The heat loss by convection, H, is therefore given by

$$H = 0{\cdot}32\ \theta_2^{5\cdot4}\ \text{B.th.u. per sq. ft. per hr.}$$

where θ_2 is the temperature difference between the spectacle belt and the surrounding air. The results are recorded in Table III.

II.—Heat Loss in Cooling Water.

The methods of determining the loss of heat in the cooling water were varied, depending largely upon plant conditions.

TABLE III.—*Heat Loss from Spectacle Belt.*

Plant.	Surface Area of Zone. Sq. ft.	Av. Temp. °F.	Av. Temp. °C.	Air Temp. °F.	Air Temp. °C.	Heat Loss. B.th.u. per hr. Radiation.	Heat Loss. B.th.u. per hr. Convection.	Heat Loss. B.th.u. per hr. Total.	Heat Loss per sq. ft. per hr.
A.	195					Not determined		32,170	165*
B. (1st test)	201	155	68·3	75·9	24·4	20,260	15,240	35,500	177
B. (2nd test)	201	122·9	50·5	40·7	4·8	17,470	15,920	33,390	166
C.	433	156	68·9	60	15·6	50,900	41,700	92,600	204
D.	306	101·8	38·8	41·6	5·3	18,420	16,420	34,840	114

* Since a direct test was not made on the spectacle belt at Plant *A*, the value of 32,170 B.th.u. per hr. as the heat loss from the spectacle belt has been derived by taking the average loss per sq. ft. per hr. obtained from the other four determinations and multiplying by the area of the spectacle belt at that plant, namely, 195 sq. ft.

A summary of the procedure at each furnace is given. The results obtained are tabulated below:

Plant.	Flow of Cooling Water. Gal. per min.	Heat Loss in Cooling Water. B.th.u. per hr.
A	588·0	4,005,000
B (1st test)	489·9	4,596,000
B (2nd test)	465·8	4,280,000
C	944·0	5,120,000
D	1540·1	7,032,000

(i) *Plant B.*—The whole of the furnace cooling water was diverted through a wooden trough, 20 ft. long, 1 ft. 10 in. wide, and 1 ft. 5 in. high, having at its discharge end a 90° V notch constructed from $\frac{1}{8}$-in. steel plate.

H, the height of the water above the sill of the notch, was measured at regular intervals with a hook gauge reading to 0·01 in., fitted 4 ft. from the V. The velocity of the water in the trough was about 0·5 ft. per sec. and its volume was calculated from the expression:

$$\text{Volume (cu. ft. per min.)} = 2{\cdot}56\ H^{5/2} \times 60.$$

where *H* was measured in ft.

The temperature of the water entering and leaving the furnace was recorded throughout the test period of 7 days.

(ii) *Plant C.*—The total volume of water leaving the system was measured over a 90° V notch inserted in a concrete culvert, 2 ft. 6 in. high and 2 ft. wide. The amount of cooling water coming into this culvert from hot blast main and stove valves was determined separately by timing the rate of flow of water from each exit pipe into a 20-gallon container, using a stop watch reading to $\frac{1}{5}$ sec. The average result of three successive tests was taken on each pipe. Requisite measurements of water volumes and temperatures were made over a period of 5 days, and, using the average values of each, a simple heat balance was constructed,

from which the heat carried away in the water used on the furnace was calculated.

(iii) *Plant D.*—On examination, it was found impracticable to apply the weir method of measuring water volumes at this furnace. The determination of the heat loss was divided into four convenient sections, namely:

(*a*) In the cigar coolers.
(*b*) In water leaving a trough in the bottom of the bosh (from bosh tuyeres, coolers and sprays).
(*c*) In water leaving the main bosh trough (from hearth tuyeres, coolers, and plate coolers).
(*d*) In water leaving the hearth trough (from hearth sprays).

The rate of flow of water from the individual pipes comprising sections (*a*), (*b*), and (*c*) was timed into a vessel calibrated in 2, 10, 20, and 30 imperial gallons, using a stop watch reading to $\frac{1}{10}$ sec. Three successive readings of the time of flow and temperature of the inlet and outlet water were averaged, and the heat flow from each pipe was calculated. The water from (*a*), (*b*) and (*c*) was carried from the furnace along a trough of rectangular cross-section. A check on the volume of water used was made by measuring off a 14-ft. length of this trough and determining, first, the rate of water-flow through it by timing 5 depth floats (oranges) along the measured length, and, secondly, finding the average cross-sectional area of the stream.

The actual flow obtained as the sum of the individual flows in the pipes was 1,277 gal. per min. As measured by the check, it was 1,307 gal. per min.

This test may be said therefore to offer confirmatory evidence of the value of the depth float method of measuring water flow employed to determine the flow of water in the hearth trough, and also used at Plant *A*.

Since the experimental work at Plant *D* was somewhat laborious, the tests extending over a period of 3 weeks, the measurements were therefore repeated on 16 pipes selected at random after completing a survey. In only three of these did the duplicates differ by more than 3 per cent. from the original. Where large differences in the rate of flow occurred, it was found that the temperature changes tended to equalise the total heat loss from that particular pipe.

The distribution of heat loss is given in Table IV.

III.—Heat Loss by Conduction to the Ground.

At each furnace, three or four holes, each 4 ft. deep and 2 to 3 in. in diam., were drilled at points round the furnace hearth and equidistant from the hearth shell (this distance varied slightly for each furnace, depending on the arrangement of the surrounding structure). From the diagrams of the furnace lines, it will be seen that the bottom of each hole could be considered

TABLE IV.—*Distribution of Heat Loss in Cooling Water at Plant D.*

	Flow. Gal. per min.	Loss. B.th.u. per hr.	Percentage of Total Loss.	
(*a*) Shaft (cigar coolers)				
Top set, 70 . . .	62·5	1,588,680	22·1	29·5
Bottom set, 70 . . .	35·7	522,000	7·4	
(*b*) Bosh (4 exit pipes)				
Sprays & No. 3 bosh cooler.	83·6	966,900	13·8	21·5
5 bosh tuyeres . . .	101·5	466,760	6·3	
4 bosh coolers . . .	52·2	65,880	0·9	
Other coolers . . .	39·6	35,760	0·5	
(*c*) Hearth.				
10 tuyeres. . . .	230·9	1,507,500	21·5	49·0
10 coolers	162·8	372,480	5·3	
33 plate coolers . . .	602·1	1,101,480	15·7	
2 slag notches . . .	30·6	163,320	2·3	
Hearth sprays . . .	138·6	291,600	4·2	
Total . .	1,540·1	7,032,360	100·0	

as being situated on a hemisphere concentric with the hearth considered as a hemisphere.

Temperatures were taken at the bottom of each hole at regular intervals during a period of 2 or 3 days, by inserting a mercury-filled copper tube containing a thermometer, sealing the hole for 10 to 15 min. and reading the temperature as quickly as possible on removal. At a later stage in the tests, a tube manufactured from 1-in. wrought iron tubing was used successfully by extending the period during which the tube was down the hole and minimising the time of transference from hole to hole.

The temperatures recorded for the holes at the various plants are recorded in Table V.

TABLE V.—*Temperature in Sub-Structure of Furnaces.*

Plant.	Distance From Ring of Holes to Centre Line of Furnace. Ft. R_2	Furnace Hearth "Hemisphere" Radius. Ft. R_1	Temp., ° F., Down Hole No.—				Average Temp.	
			1.	2.	3.	4.	° F.	° C.
A.	18·18	..	..	..	..	..	..	80
	22·70	5·63	..	..	..	..	..	52
B.	24·25	6·00	72·5	68·8	94·1	79·8	78·8	26·0
B.	24·25	6·00	69·2	76·3	..	84·8	76·7	24·8
C.	26·5	8·50	142·1	146·1	158·3	142·9	147·5	64·2
*D.**	24·25	7·25	156·8	115·3	127·2	..	133	56·1

* Holes only 2 ft. deep at Plant *D.*

Ingersoll and Zobell,[1] discussing the flow of heat in a hollow sphere, give a formula for the total heat conducted:

$$Q = \frac{4\pi K(\theta_3 - \theta_4) r_1 r_2}{(r_2 - r_1)} \text{ B.th.u. per hr.}$$

that is $$\frac{2\pi K(\theta_3 - \theta_4) r_1 r_2}{(r_2 - r_1)} \text{ for a hemisphere} \quad . \quad . \quad . \quad (1)$$

in which $2\pi r_1 r_2$ is the area of the geometric mean hemisphere, and r_1 and r_2, and θ_3 and θ_4, are the radii and temperatures of the internal and external hemispherical surfaces, respectively. K, the conductivity of the material considered, is taken as 0·8 for the mixture of firebrick and concrete.

As can be seen from the diagrams of the furnace lines, however, a portion of the external hemisphere is above ground level, hence no heat is conducted through this portion. The total surface area of the outer hemisphere is $2\pi r_2^2$, and if h is the maximum depth of the portion below ground level then $2\pi r_2 h$ is the surface area of this portion of the hemisphere, that is:

$$\frac{\text{Surface area below ground level}}{\text{Total surface area}} = \frac{2\pi r_2 h}{2\pi r_2^2} = \frac{h}{r_2} \quad . \quad . \quad . \quad (2)$$

Hence by using the factor (2) in the expression (1), we can allow for the area of the outer hemisphere in which no conduction takes place, giving a general expression:

$$\frac{2\pi K(\theta_3 - \theta_4) r_1 h}{(r_2 - r_1)} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where θ_3 is the temperature of the furnace hearth (assumed to be 1,600° C. = 2,912° F.) and θ_4 is the average temperature down the holes. The values obtained for the heat loss by conduction through the ground using the expression (3) were:

Plant	*A*.	101,050 B.th.u. per hr.
	B. (1st Test) . . .	51,500 „ „ „
	B. (2nd Test) . . .	51,560 „ „ „
	C.	108,200 „ „ „
	D.	83,670 „ „ „

Summary of Results.

A summary of the total external heat loss calculated from the five tests made is given in Table VI. The results are also calculated in terms of B.th.u. per lb. of iron produced and B.th.u. per sq. ft. of hearth area per hr. and represented graphically in Figs. 5 and 6. The variation of shaft temperature with the distance

[1] "Mathematical Theory of Conduction," London, p. 26.

TABLE VI.—*External Heat Loss from Various Furnaces.*

Plant:	*A.*		*B.*		*B.*		*C.*		*D.*	
Output: Type:	750 Tons per Week. Foundry.		550 Tons per Week. Basic.		990 Tons per Week. Basic.		2,800 Tons per Week. Hematite.		1,900 Tons per Week. Basic.	
	B.th.u. per hr.	% of Total.	B.th.u. per hr.	% of Total.	B.th.u. per hr.	% of Total.	B.th.u. per hr.	% of Total.	B.th.u. per hr.	% of Total.
A. Loss from 1. By radiation . . shaft. 2. By forced convection .	382,100 345,090	7·8 7·1	104,980 80,240	2·1 1·6	63,310 111,350	1·4 2·4	308,800 536,740	5·0 8·7	349,680 427,200	4·4 5·4
B. Loss from 1. By radiation . . spectacle 2. By convection . . belt.	32,170	0·7	20,260 15,240	0·4 0·3	17,470 15,920	0·4 0·3	50,900 41,700	0·8 0·7	18,420 16,420	0·2 0·2
C. Loss in cooling water . . .	4,005,000	82·4	4,596,000	94·0	4,280,000	93·4	5,120,940	83·0	7,032,360	88·7
D. Loss from 1. By radiation . . hearth shell 2. By convection . .	..	..	16,790 10,760	0·3 0·2	17,180 13,980	0·4 0·3	..	..	..	..
E. Loss by conduction through ground .	98,080	2·6	51,500	1·1	51,560	1·1	108,200	1·8	83,670	1·1
TOTAL . . .	4,862,440		4,895,770		4,570,770		6,167,280		7,927,750	
Iron, Lb. per hr. produced . . .	10,000		7,340		13,200		37,400		25,300	
Hearth area, Sq. ft. . . .	99·5		113		113		227		168	
B.th.u. per lb. iron produced . .	486		666		347		165		313*	
B.th.u. per sq. ft. hearth area per hr. .	49,000		43,250		40,500		27,100		47,200*	

* Deducting 2,609,640 B.th.u. per hr. as the heat loss in water supplying cigar coolers on shaft, bosh tuyeres and bosh coolers, the value of 313 B.th.u. per lb. of iron would become 208 B.th.u. per lb. of iron produced. The heat loss per sq. ft. of hearth area per hr. is then 31,700.

from the bottom of the shaft is recorded in Fig. 7, and the air temperature differences between the shaft and the surrounding air at various shaft heights have been included on the same diagram. The operating data at each furnace are given in Tables VII. and VIII.

TABLE VII.—*Furnace Operating Data.*

Plant:	*A.*	*B.* (1st Test.)	*B.* (2nd Test.)	*C.*	*D.*
Average weekly output during test. Tons	750	550	990	2800	1935
Type of pig	Foundry	Basic	Basic	Hematite	Basic
Cwt. per ton of pig—					
Coke consumption	26·3	31·2	28·0	20·0	28·5
Ore and auxiliaries	75·3	67·3	61·2	36·0	74·4
Stone	0·2	10·5	7·3	9·0	Nil
Slag produced	24·7	28·1	23·0	11·5	26·2
Yield from burden (less coke). %	24	25	29	44	27·3
Blast temp. ° F.	1220	1180	1080	950–1350	945
Blast press. Lb. per sq. in.	6·4	3·4	5–6½	11–12	9½
Blast volume. Cu. ft. per min.	14000	13300	16700	34400	35500
Top gas. Temp. ° F.	160	300–500	250–450	350–550	240–550

DISCUSSION OF RESULTS.

(1) *General.*

In the tests at Plant *A* previously reported[1] the results obtained were found to be considerably smaller than the values given by the previous workers, who obtained their values by

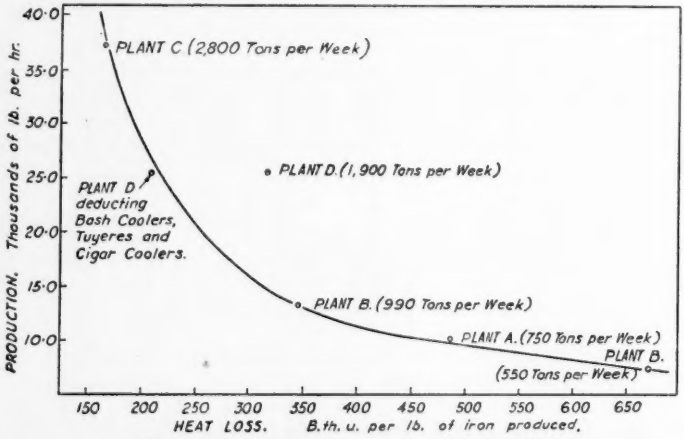
PRODUCTION. Thousands of lb. per hr.
40·0
35·0
30·0
25·0
20·0
15·0
10·0
PLANT C (2,800 Tons per Week)
PLANT D. (1,900 Tons per Week)
PLANT D deducting Bash Coolers, Tuyeres and Cigar Coolers.
PLANT B. (990 Tons per Week)
PLANT A. (750 Tons per Week)
PLANT B. (550 Tons per Week)
150 200 250 300 350 400 450 500 550 600 650
HEAT LOSS. B.th.u. per lb. of iron produced.

FIG. 5.—External Heat Loss from Blast-Furnaces.

[1] Marshall, *loc. cit.*, p. 139.

TABLE VIII.—*Furnace Operating Data.*

TABLE VIII.—*Furnace Operating Data.*

Plant:	*A.*	*B.* (1st Test.)	B. (2nd Test.)	*C.*	*D.*
Life of lining. Weeks:	263	176	211	91	349
Iron produced on lining. Tons:	190,212	117,533	144,216	199,969	564,100
Furnace lines:					
Height	74 ft. 6 in.	71 ft. 0 in.		80 ft. 0 in.	71 ft. 0 in.
Hearth diameter	11 ft. 3 in.	12 ft. 0 in.		17 ft. 0 in.	14 ft. 6 in.
Bosh diameter	17 ft. 0 in.	18 ft. 6 in.		21 ft. 6 in.	21 ft. 0 in.
Bosh height	13 ft. 0 in.	10 ft. 3 in.	As in test 1.	11 ft. 8 in.	13 ft. 3 in.
Bosh angle	77° 32′	72° 20′		79° 5′	76° 13′
Surface area. Sq. ft. 1. shaft	3,560	3,643		4,856	4,537
2. bosh	605	565		840	694
3. spectacle belt	195	201		433	306
4. hearth	555	678		594	640
	1,355	1,444		1,867	1,640
Thickness of lining when blown in:					
Shaft. Top	3 ft. 3 in.	4 ft. 6 in.		4 ft. 3 in.	4 ft. 3 in.
Bottom	4 ft. 0 in.	4 ft. 9 in.		3 ft. 9 in.	4 ft. 0 in.
Bosh	13½ in.	9 in.		20 in.	15 in.
Hearth. Top	2 ft. 6 in.	1 ft. 0½ in.		3 ft. 0 in.	2 ft. 6 in.
Bottom	4 ft. 0 in.	2 ft. 7½ in.		3 ft. 3½ in.	3 ft. 3 in.
Water cooling.					
No. of tuyeres and coolers	8	10		10	15 {5 bosh, 10 hearth.
Bosh sprays	3 rings.	4 rings.		3 rings.	1 full ring, 5 smaller.
Hearth	Internal plate coolers.	Internal plate coolers.		Externally cooled, 1 ring of sprays.	Externally cooled, 2 rings of sprays.
Plate coolers on spectacle belt	2 rows of 8—Top row off in 1931.	18 coolers in 2 rows.		1 row of 24 coolers under tuyere breast. 1 row of 12 flat coolers under tuyeres.	33 plate coolers in in 4 rows.
Shaft	..	..		..	140 cigar coolers.
Volume of cooling water. Gal. per min.	588	489·9	465·8	944	1,540
Insulation between furnace lining and outer shell.	Slag wool.	Mixture of crushed firebrick and sawdust.		Sand.	Slag wool.

difference. Since the heat loss in B.th.u. per lb. of iron in all the present tests was found, with one exception, to be less than the values obtained at Plant *A*, the conclusion previously drawn that the external heat loss of a blast furnace may have been over-estimated in the past, has been confirmed. It follows therefore that there must be some other explanation of the relatively large differences between the heat input and that accounted for in the thermal balances of blast furnaces which have been constructed.

Fig. 5 represents the relationship between the external heat loss per lb. of iron produced and the output at the various furnaces

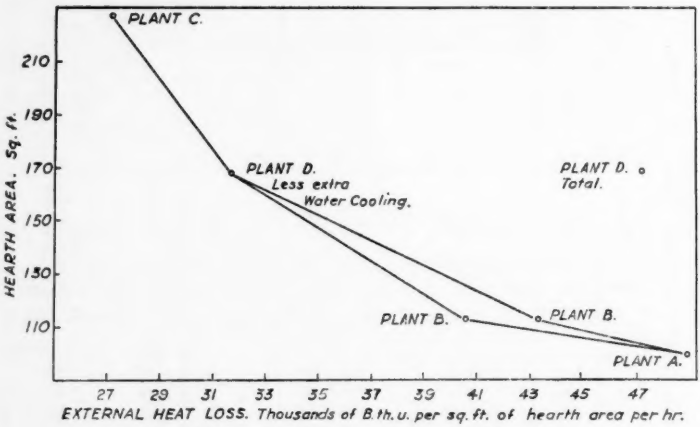

FIG. 6.—Influence of Furnace Size on External Heat Loss.

examined. The total external heat loss was determined at Plant *B* for two widely varying sets of operating conditions, the iron outputs during the two tests being 550 and 990 tons per week. The values obtained were very similar, and suggested that the external heat loss is not materially affected by changes in furnace operation, or, alternatively, the total heat loss from any particular furnace is practically constant for all operating conditions.

The relationship between the heat loss in B.th.u. per lb. of iron and the production at any one furnace may therefore be represented graphically by a simple hyperbola. In Fig. 5 the heat loss in B.th.u. per lb. of iron produced is plotted against the production for all the furnaces examined, and the resulting curve is undoubtedly of the type suggested by the results at Plant *B*. The furnace at Plant *D* had additional water cooling for bosh tuyeres and cigar coolers, and it seems significant that by simply

deducting these additional heat losses from the total loss, the results fell closely in line with those obtained at other plants where these devices were not in use. Fig. 5 can on these grounds be used as a basis for determining the external heat loss at different furnaces where the water-cooling arrangements do not differ greatly from those employed at the furnaces examined.

The relationship between external heat loss and furnace size is illustrated in Fig. 6, in which the hearth area is taken as a factor representing the furnace size. It will be seen that the heat loss in B.th.u. per sq. ft. of hearth area tends to approach a minimum value as the hearth area increases.

(2) *Heat Loss from the Shaft.*

It will be seen from Table VI. that the loss of heat from the shaft forms a surprisingly small proportion of the total heat loss from each furnace, ranging from a minimum value of 3·7 per cent. of the total loss at Plant *B* to a maximum value of 15 per cent. at Plant *A*.

(*a*) *Shell Temperatures.*—Fig. 7 illustrates the variation of the average temperature for each band of plates from the lintel plate upwards. In general it was found that, starting at the bottom of the shaft, the average shell temperatures increased rapidly to a maximum value and then showed a fairly regular decrease to the throat of the furnace. The furnace at Plant *A* has since been taken out of blast because of a lining collapse. On examination, the shaft lining was found to be badly slagged and practically eaten through to the shell at the third band of plates from the bottom, that is, the precise position of the peak in the shell temperature diagram. Both above and below this weak point the lining was in a much better condition. Since the lines of the four furnaces examined vary considerably it was thought that the distance of this zone from the tuyeres might be important. These distances, deduced as closely as possible from the complete shaft surveys and not from the average temperatures given in Table I., were as follows :

Plant :	*A*.	*B*. 1st Test	*B*. 2nd Test	*C*.	*D*.
Distance of hot zone on shaft from tuyeres. Ft.	27	25·5	25·5	17·3	26·5*

* 26·5 ft. from bosh tuyeres, that is, 37·5 ft. from hearth tuyeres.

It will be noticed that the position of this hot zone at Plant *C* is much nearer the tuyeres than in the other three cases. For Plants *A*, *B*, and *D*, the distances are all very similar, if at Plant *D*, the nearest set of tuyeres, that is, the bosh tuyeres, are considered. It is interesting to note that the shaft temperature surveys at Plant *D* gave some indication of a second hot zone some 10 to 15 ft. below the first, that is, at approximately the same distance

(11 ft.) as that between the hearth and bosh tuyeres (Fig. 4). Plants *A*, *B* and *D* all operate on similar types of lean ores and

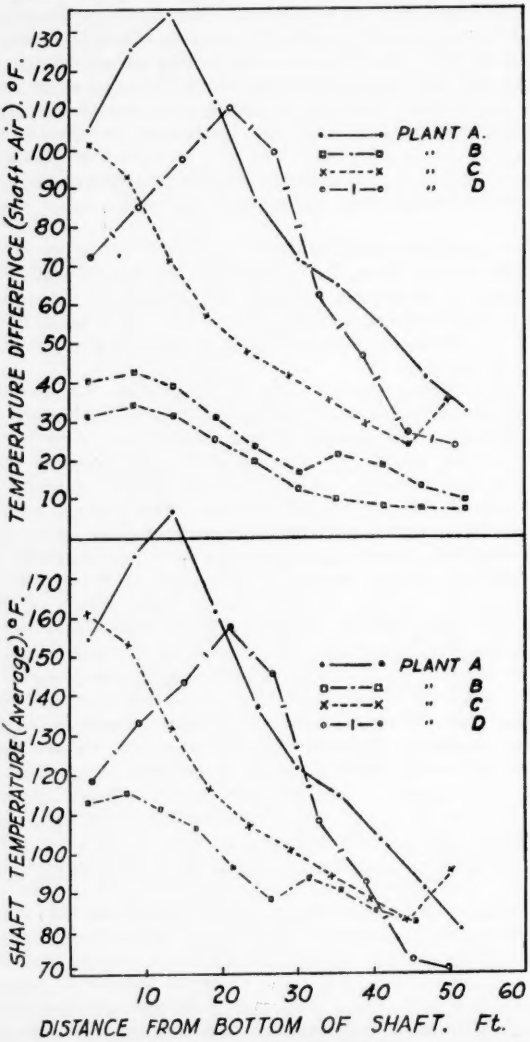

FIG. 7.—Average Shell Temperature

Plant *C* on a much richer one. It seems probable that this is an important factor in determining the position of this hot zone at which the shaft lining is attacked most. The use of bosh tuyeres seems to move this point higher up the furnace and, moreover, to give two points of attack. Whether or not this zone marks the point at which the initial formation of slag begins and its pasty nature at this stage renders the possibility of lining attack more probable by increasing the time of contact of slag and lining, is a point which cannot be decided on the evidence available.

Water cooling of the shaft by cigar coolers has been adopted at several plants. The results of these tests suggest that considerable reductions in both the external heat loss and in the amount of water used could be made by restricting this method of cooling to the hot zones of the shaft. The value of this type of cooling in prolonging the life of a lining is at present rather problematical, and can only be determined by actual tests.

(*b*) *Effect of Rate of Drive.*—Two series of tests were carried out at Plant *B*, one when the furnace was working with a reduced output of 550 tons of basic iron per week and one when the furnace was producing its normal 1,000 tons per week. The total heat loss from the shaft was 185,220 B.th.u. per hr. in the first test and 174,660 B.th.u. per hr. in the second. It seems probable therefore that the heat loss from the shaft of this particular furnace is not influenced by the rate of drive. The increase in the shell temperatures due to low stock-line height during the first test is clearly indicated in Fig. 7.

(*c*) *The Influence of the Life of the Shaft Lining.*—The variation of the heat loss per unit area of the shaft from furnace to furnace as given in Table IX. calls for a certain amount of explanation.

TABLE IX.—*Heat Loss from Shaft.*

Plant.	No. of Weeks in Blast.	Total Make of Iron, Tons.	Total Throughput Burden and Coke. Tons.	Thickness of New Lining.		Heat Loss per sq. ft.	
				Top.	Bottom.	(*a*) B.th.u. per hr.	(*b*) B.th.u. per ton Throughput per hr.
				Ft. in.	Ft. in.		
A.	263	190,212	1,037,000	3 3	4 0	204	8·7
B.	176	117,533	618,000	4 0	4 9	51	2·5
B.	211	144,216	737,000			48	2·3
C.	91	199,969	656,000	4 3	3 9	176	4·2
D.	349	564,100	3,000,000	4 3	4 0	172*	3·4

*Including the loss of heat on the shaft in the cigar coolers, the loss of heat per unit area is 631 B.th.u. per hr. or 12·4 B.th.u. per sq. ft. per ton of throughput per hr.

The extremely high value of 631 B.th.u. per sq. ft. of shaft per hr. obtained as the loss of heat from the shaft at Plant *D* may be ascribed to the fact that this lining is considerably older than the others and to the use of bosh tuyeres and cigar coolers. Plant *A*, the second highest in the list in age and total throughput, also has the second highest heat loss. The values obtained at Plant *B* were extraordinarily low. This plant had the thickest lining when blown in, and since it has been operated for considerable periods with a very greatly reduced rate of drive, it is probable that the original lines have been less altered than at the other plants. A period of 35 weeks elapsed between the two tests made at this plant, but the heat loss per unit area of shaft was actually greater during the first test than the second. The increase in heat loss due to the lower stock-line height during the first test was greater than any possible increase due to wear of lining between the determinations.

At Plants *A*, *B* and *D*, the values of the total iron made on the lining are more or less directly comparable since the ores used were of the same type. Plant *C*, however, used ores giving a much greater iron yield. The shaft at Plant *C* had a relatively high heat loss, considering its comparatively short life. It will be observed from the table of operating results that this furnace is driven at a much greater rate than the other three. The results obtained at Plants *B* and *C* suggest that the rate of drive of the furnace may be an important factor governing the shaft heat losses.

From the limited number of results available it is not possible to draw final conclusions on the relationship between the throughput of materials and the heat loss from the shaft. At Plants *A* and *D*, however, where the linings have been in use for long periods and the highest throughput of materials has been attained, the shaft heat losses per unit area (including water-cooling losses) were much greater than on the other two furnaces. The lining at Plant *A* has collapsed since the tests were made and it seems reasonable to suppose that the additional water cooling on the shaft at Plant *D* has played some part in extending the life of the lining although it has increased the shaft heat loss. It may be that the high value obtained for the heat loss from the shaft at Plant *A*, expressed as B.th.u. per sq. ft. per ton of throughput, is an indication of the lining collapse which has occurred at this plant since the tests were completed.

(*d*) *Effect of Air Temperature, Wind Velocity and Furnace Site.*—In Table X. an attempt has been made to indicate the cooling effect of the wind incident on the shafts of Plants *C* and *D* by calculating the consumption of fuel required to make good the shaft losses. For this purpose the following assumptions have been made :

(1) The heat required to make good the shaft losses is generated as heat available in the hearth.

(2) The coke charged contains 85 per cent. of carbon, 1 lb. of which generates 5,994 B.th.u. (including the sensible heat in the blast) by combustion to CO. Of this total heat generated an arbitrary proportion of one-quarter has been taken as the heat available to meet the external heat loss requirements.

TABLE X.—*Cooling Effect of Wind.*

Plant.	Survey.	Wind Velocity. Ft. per sec.	Heat Loss. B.th.u. per hr.			Lb. of Carbon per hr.	Cwt. Coke Charged To Meet The Shaft Heat Loss.	
			Radiation.	Convection.	Total.		Hour.	Week.
C.	1	17·8	308,800	536,740	845,540	563	5·94	998
	2	28·6	269,050	711,360	980,410	653	6·89	1,158
D.	1	15·0	333,420	533,220	866,640	576	6·08	1,020
	2	15·7	321,910	524,550	846,460	564	5·95	1,000
	3	2·9	393,710	223,820	617,530	411	4·33	727

From the table it will be seen that at Plant *C* an increase in wind velocity from a value of 17·8 ft. per sec. to the exceptionally high value of 28·6 ft. per sec. was equivalent to an additional coke consumption of 160 cwt. per week. At Plant *D* an increase in wind velocity of from 2·9 ft. per sec. to 15·0 ft. per sec. was equivalent to an additional coke consumption of 283 cwt. per week, but the wind velocities considered represent extreme conditions.

Since there is usually a considerable amount of waste heat available in the furnace shaft to meet the external heat loss, the calculated coke consumptions are probably the maximum possible, and in all probability the extra fuel required to meet the shaft losses is considerably less than the figures given in Table X.

The average yearly wind velocities deduced from the monthly weather report of the Meteorological Office, 1930, for the various iron-making districts ranged from 12·7 to 18·3 ft. per sec.

It will be noticed that where a cooling wind reduces the shaft temperatures the resulting decrease in the radiation losses is more than counterbalanced by the increase in the convection losses.

(*e*) *Shaft Insulation.*—The results of these tests are of particular interest since shaft insulation is now being considered as a means of improving furnace operation. The very low values obtained for the heat loss from the shaft suggest that shaft insulation as

a means of reducing the external heat loss from the shaft is unnecessary.

On the other hand, it seems probable that shaft insulation may be serviceable in prolonging the life of the lining by :

(*a*) Ensuring a more uniform temperature gradient through the lining and reducing the amount of spalling.

(*b*) Producing a higher temperature on the inner surface of the lining. This would probably produce an increase in the amount of vitrification of the inner surface, rendering it less liable to wear by abrasion and less permeable to the passage of gases and the disintegration resulting from this.

(3) *Heat Loss in Cooling Water.*

The heat loss in the cooling water constitutes by far the major portion of the total external heat loss, ranging from 82·4 per cent. of the total at Plant *A* to a maximum value of 94 per cent. at Plant *B*. The results are recorded in Table XI.

TABLE XI.—*Heat Loss in Cooling Water.*

Plant.	Vol. of Water Used. Gal. per min.	Total Heat Loss. B.th.u. per hr.	Temp. Diff. Inlet and Outlet. ° F.	Surface Area, Sq. ft.				Heat Loss, B.th.u. per sq. ft. per hr.	Water Used, Gall. per sq. ft. per min.
				Bosh.	Spectacle Belt.	Hearth.	Total.		
A.	589	4,005,000	11·3	605	194	555	1,355	2950	0·435
B.	490	4,596,000	15·6	565	201	678	1,444	3170	0·339
B.	466	4,280,000	15·3	565	201	678	1,444	2960	0·322
C.	944	5,120,000	9·0	840	433	594	1,867	2750	0·505
*D.**	1236	4,422,000	6·0	694	306	640	1,640	2700	0·754

* This value given for Plant *D* does not include the heat loss in cooling water from bosh tuyeres and coolers and the cigar coolers on the shaft. The total heat loss including these was 7,032,000 B.th.u. per hr. The figure given in the table for the water-cooling losses is comparable with those used on the other furnaces.

An examination of the distribution of the cooling-water losses made at Plant *D* has shown the chief sources of loss to be the tuyeres, the plate coolers on the spectacle belt and the bosh sprays, excluding the high loss in the cigar coolers on the shaft peculiar to this furnace.

Considering the varied nature of the methods of water cooling employed at the four furnaces examined, the results obtained expressed as heat loss per unit of cooling surface area show a remarkable similarity. There is, however, a tendency for the heat loss per unit area to decrease as the total surface area increases. This tendency may have been masked by another factor, namely, the amount of cooling water used. The volume of cooling water used for different furnaces appears to be fixed arbitrarily, without any relationship to the amount of water

cooling necessary. Since greater areas are water cooled at Plants *C* and *D*, it follows naturally that more water is needed, but the volumes of water used at these two plants are so great compared with those used at Plants *A* and *B* that it seems probable that more heat than necessary has been carried away in this manner. This view is supported by the very low temperature difference between the inlet and outlet water and the greater amounts of water used per unit surface area at Plants *C* and *D* compared with the values obtained at Plants *A* and *B*. If this is so, the normal heat loss in the cooling water at Plants *B* and *C* would be less than those obtained, and the heat loss per unit area would show a still greater decrease. These observations suggest that a close scrutiny of the amounts of cooling water used should be made at blast-furnace plants, for since the major portion of the external heat loss occurs in the cooling water, it is possible that considerable reductions in this loss might be made by undertaking a careful control of the cooling water used, apart from economies to be derived from reducing the handling costs. A 10 per cent. reduction on a total heat loss of 5,000,000 B.th.u. per hr. would give a corresponding reduction in the coke charged to meet these losses of 29·9 tons per week, as calculated by the methods outlined under the section dealing with shaft heat losses. From a systematic investigation into the amount of cooling water used, and the temperature rise involved by its application to any one furnace, the effect of varying the quantity could be observed and the amount of water cooling consistent with safe operation and minimum heat loss be determined. It seems desirable that an investigation should be made into the relative efficiency of external spray cooling and the use of internal block or plate coolers, with particular reference to their effects on the furnace lining. On all the furnaces examined, spray cooling is used on the bosh where the lining is thinnest with apparently satisfactory results. Among the advantages resulting from the use of spray coolers are :

(1) A more uniform temperature distribution through the lining ;

(2) Greater ease of operation and replacement ;

(3) Improved facilities for experimental observations.

It is possible, therefore, that the improved facilities for observation and control resulting from the replacement of plate coolers by sprays wherever practicable would yield ultimate reductions of the external heat loss and of the amount of cooling water used.

(4) *Heat Loss by Conduction Through Ground.*

The furnace hearths at Plants *B*, *C* and *D* are entirely above ground level, but the hearth at Plant *A* is almost surrounded by

refractory brickwork. The heat loss by conduction through the ground attains a maximum value of 2·1 per cent. of the total loss at Plant *A*, and because of the very low value obtained at each furnace, it may be considered relatively unimportant. The following sources of error in the calculation of this loss may be noted:

(*a*) The points at which ground temperatures were measured (see diagrams) occur on radial lines (from centre of hearth hemisphere) which pass through (1) the side of the hearth which is water-cooled, and (2) air. Radial transmission of heat is therefore interrupted and the ground temperatures as measured may be low, and hence the heat loss recorded too high.

(*b*) The effective area of the outer hemisphere through which radial transmission of heat takes place should be that area bounded by radial lines (from the centre of the hearth hemisphere) which are uninterrupted by either the hearth casing or air. This area is less than the effective area used in the calculation, and therefore the heat loss again is too high.

By ignoring both these factors, the heat loss calculated is too high, but if allowance were made for the second source of error, that portion of the ground outside the area defined in (*b*) would be ignored. As heat is definitely conducted across this zone, it is felt that the figure given for the heat loss by conduction may be accepted as substantially correct.

Conclusions.

(1) The results of further determinations of the external heat loss from four blast-furnaces have confirmed the conclusion drawn from a test described in a previous paper,[1] that this loss has previously been overestimated and occurs mainly in the cooling water. In all cases the heat carried away in the cooling water amounted to over 82 per cent. of the total loss.

(2) The tests have indicated that the total external heat loss is not markedly influenced by differences in furnace operation, except where such changes create a necessity for additional water-cooling, such as the use of bosh tuyeres or cigar coolers on the shaft.

(3) It has been found that the heat loss per unit surface area of the water-cooled zones (bosh, spectacle belt, and hearth) is very similar on all the furnaces examined, but it does show a tendency to decrease slightly on the larger furnaces. It follows therefore that the total surface area of the water-cooled regions on a furnace is an important factor governing the total external heat loss from that furnace. One furnace examined incurred additional water-cooling losses in bosh tuyeres and cigar coolers. The results at this plant fell closely in line with

[1] Marshall, *loc. cit.*

those obtained at others when due allowance was made for the additional heat loss involved by the extra cooling.

There is a very considerable variation in the amounts of cooling water used from plant to plant, even where similar types of cooling are employed. It is possible therefore that considerable economies of both heat and water might be effected by making a systematic examination of the distribution of the heat loss in the cooling water at each furnace.

(4) The heat loss from the shaft of each furnace constitutes a relatively small proportion of the total loss. The cooling effect of strong winds and the influence of exposed furnace sites are therefore correspondingly small factors governing the total heat loss. The experimental results suggest that the value of shaft insulation lies not in the actual reduction of the shaft heat losses, but in the possibility of prolonging the life of the furnace lining. Although the heat loss per unit of shaft area tends to increase as the lining ages, there is some evidence that the rate of drive of a furnace plays a more important part in governing the loss of heat from the shaft.

(5) At three of the furnaces, operating on similar types of lean ores, it has been found that the maximum temperatures recorded on the shaft were approximately equidistant from the nearest tuyeres, and in one of the furnaces, where a collapse of the lining occurred subsequently, this took place at the zone of maximum temperature. It is interesting to note that on the furnace using bosh tuyeres the maximum shaft temperatures were much higher up the shaft than on any other furnace, but were still at approximately the same distance from the nearest tuyere, that is, the bosh tuyeres. On one furnace, using richer ores, this distance became much less. These observations suggest that water cooling of the shaft which is now coming into use could profitably be restricted to that part of the shaft around the maximum shell temperature zone.

The plants at which the experimental work was carried out in the period 1933–34 were as follows:

Plant *A*. Messrs. Newton Chambers and Co., Ltd., Thorncliffe, Sheffield.
Plant *B*. The Park Gate Iron and Steel Co., Ltd., Rotherham (No. 1 furnace).
Plant C.* The Workington Iron and Steel Co., Workington (No. 2 furnace, Derwent).
Plant D.* Frodingham Iron and Steel Co., Ltd., Scunthorpe (No. 5 furnace, Appleby).
* The United Steel Companies, Ltd.

The author desires to thank the managements of these firms for permission to conduct the research and publish the results, and those members of their staffs whose whole-hearted co-operation made the experimental work practicable.

DISCUSSION.

Mr. R. A. HACKING (Rotherham) said that in 1933 Dr. Marshall was deservedly congratulated on having made for the first time in the history of the blast-furnace a direct determination of its external heat loss. He thought that all would agree that the warmest thanks were again due to the author for his present extension of his investigations to three further typical examples of British blast-furnace practice. Personally, as one who had had the privilege of coming in contact with Dr. Marshall during the course of the experiments described, he would like to express his appreciation of the care, energy, and—one might add—agility displayed by him in making the hundreds of readings necessary for each of the test runs.

These further determinations had certainly confirmed the conclusion drawn from the author's original paper, to the effect that previous estimations of the external heat loss of a blast-furnace had been greatly exaggerated, no doubt owing to the fact that they were estimated by difference from the complex thermal balance sheet of the whole process, and, as a result, were subject to an accumulation of errors over all the other items. When one reflected that some of the most important items on the debit and credit sides of the thermal balance sheet of a blast-furnace were based upon heats of formation, specific heats and so on, which were not known accurately or even, in some cases, approximately, it was easy to see where some of the errors might arise. It was rather significant that the discrepancy was always in the one direction, and so it would appear that the disagreement was not due to experimental error on the part of those drawing up the thermal balance sheet but rather to some intrinsic error in some of the constants used.

In Fig. 7 curves were shown giving the shell temperatures at the various plants, and it was somewhat significant that the highest peak in those temperature curves was given by Plant *A*, which was in a sheltered position and which was approaching the end of its campaign. There was one curve relative to the second test on Plant *B* which appeared to have been omitted from the lower portion of the diagram, and in addition the last two points on the two bottom curves of the upper diagram seemed to have been displaced to the right; they should actually be immediately over the corresponding points on the bottom curve of the lower diagram.

The coincidence between the peak in the shell temperature curve and the zone of greatest erosion of the inwall was very interesting. All the furnaces examined in the course of the

investigation, however, had been working for some considerable time—90 weeks or more—prior to the test runs, and the shell temperatures recorded would undoubtedly be dependent in no small degree upon the erosion which had already taken place. It would be interesting to make some similar determinations on a furnace which had just settled down after re-lining and before the inwall had had a chance to become seriously eroded.

He agreed with the author's suggestion that the zone of maximum wear probably coincided with the commencement of slag formation, but he was of the opinion that the mechanism of that attack was *via* the silicates of iron and manganese which formed at the relatively low temperatures in question, the FeO and MnO being displaced progressively, ultimately to a point approaching equilibrium, by CaO, MgO, &c., as the slag descended and attained the higher temperatures obtaining in the hearth. Slags rich in ferrous and manganous oxides were notoriously unkind to siliceous refractory materials, and he would suggest that the serious erosion occurring at that level in the furnace was due to their presence at those temperatures.

He would like further to point out that the profile of the eroded portion as seen in plan usually followed very closely the disposition of the tuyeres, even in a 10- or 12-tuyere furnace. Thus the erosion appeared to be a combination of slag attack, accelerated by the progressive removal of reaction products at the position immediately above each individual tuyere, and the erosive effect proper of the ascending gases.

The relation between the positions of the hot zones in furnaces *A*, *B* and *D* was very interesting, but was almost to be expected, because those furnaces were using ore mixtures which were very similar, with approximately the same amounts of fuel per ton of pig iron, while the blast temperatures used were about *pro rata* with the type of iron made by the respective units. The lower location of the hot zone in furnace *C* would suggest that the temperature of the gases ascending from the tuyeres fell with the distance at a more rapid rate than in the case of the other furnaces, that was, there was a much steeper gradient in the temperature curve from the tuyeres upwards. That might be due primarily to the use of hard, dense hematite ores, the delayed reduction of which by the highly endothermic direct path greatly increased the thermal demands of the bosh and lower portions of the shaft.

Mr. F. J. Bailey (London) said he had been interested in the problem of heat loss from blast-furnaces for some years, and there were two points which he would like to put forward for Dr. Marshall's consideration, because he did not think Dr. Marshall had sufficiently realised their importance.

In the first place, in any furnace one might carefully determine the external heat losses very successfully, but the amount of fuel which had actually to be burned in the furnace, in order to maintain the internal temperature when that heat loss was actually being given away to the atmosphere, was of rather a different order, as had already been pointed out in 1928, when the original paper on blast-furnace operation was given by Mr. Evans. Although the determination of the heat loss by difference from the balance sheets might undoubtedly have been in error, that was not quite the same trouble as trying to arrive at how much fuel had actually to be burned in the furnace to make good the heat loss. There had to be a wide margin, and the actual amount of fuel burned must be of the order of three to five times the amount of heat which was lost, since the gases left the higher temperature zone round the hearth, where the maximum heat loss was taking place, at a very high temperature. That energy was returned in the form of reduced ore, but that did not affect the thermal balance sheet of the furnaces.

He agreed with the suggestion that the lagging of the upper part of the shell of the furnace would help to maintain the life of the refractories, but it might have a very serious effect on that very fine interplay of mechanical reaction which was taking place in that portion of the furnace, and he thought there was something more there than the mere physical heat losses which had to be taken into account.

Mr. R. C. TUCKER (Sheffield) said that one thing which Dr. Marshall had definitely shown was that the heat loss of a blast-furnace was not nearly so important as people used to make out, and therefore that many of the so-called improvements in design were merely fads. Dr. Marshall had also shown that, of the heat loss which did take place, a surprisingly large proportion was due to water-cooling, and, in spite of that, furnaces to-day were producing iron at low rates of fuel input with thin walls and a great deal of water-cooling, as compared with the old furnaces, which had thick walls and no water-cooling, and, in other words, low heat losses. That was an important point in assessing the various factors which governed blast-furnace operation and efficiency.

Previous papers by Dr. Marshall having shown that the furnace at Plant *A* gave an abnormally low iron factor, the explanation had been advanced that the heat loss was abnormally small. That was now proved incorrect and strengthened his (Mr. Tucker's) previous contention that the cause was a chemical one.

The argument that the heat loss should be multiplied by 3 or 4 to give the heat actually required to maintain the furnace

temperature in practice surely applied to *all* furnaces and did not explain the abnormality of furnace *A*.

The heat loss of furnace *A* was 6 per cent. of the heat input :

$$\begin{aligned} &C \rightarrow CO \\ +\ &C \rightarrow CO_2 \\ +\ &\text{heat in blast.} \end{aligned}$$

A heat balance confirmed Marshall's figure closely. Hence the only abnormality in furnace *A* was *chemical*, and *full* heat balances of the other furnaces should be determined to explain why they had normal iron factors. He would like to know why Plant *A* had such an abnormally low iron factor according to the Evans method of computation.

Mr. A. F. Webber (London) said that in the first place he would like to congratulate Dr. Marshall on having carried out a piece of genuine experimental work under difficult conditions. Secondly, he thought, without depreciating purely metallurgical research in any way, that the Institute was to be congratulated in that some of the Carnegie research funds were being devoted to research work on production plant of the nature in question. In the third place, he challenged most firmly Dr. Marshall's first conclusion, that the heat loss had previously been overestimated. He did so on the ground that Dr. Marshall had not yet determined the heat loss in the cooling water, and could not do so until he had taken some account of evaporation. He (Mr. Webber) could offer no suggestion as to how that could be done in practice, but the fact remained that there were few better ways of evaporating water than by spraying it on heated metal plates in a high wind, and that on a very modest computation of the heat lost by evaporation, rating it at only one-tenth of that usual in cooling towers, the heat loss expressed on an hourly basis would be from 2 million to 2½ million B.th.u. for the plants mentioned in the paper, or roughly 50 per cent. extra on the heat loss due to heating up the water. It was clear that if there was any possibility of a 50 per cent. increase in that—and it could not be disproved and was a very low estimate—it was at present, at any rate, much too early to say that the heat loss had been overestimated. Sooner or later the question would have to be tackled, and, in view of the preponderating proportion of the heat loss which was carried away by the cooling water, that would seem to be a point of the utmost importance.

It was not always clear, from the presentation of the results of Dr. Marshall's experimental work, what methods had been adopted to calculate the final figures.

The heat loss due to radiation from the shaft appeared to be calculated from an average temperature based on the arithmetic mean of the varying temperatures observed, whereas, as stated

in his (Mr. Webber's) criticism of Dr. Marshall's earlier paper, allowance should be made for the facts that the radiation loss varied as the fourth power of the temperature and that the hottest belts were also those of greatest diameter. That correction might amount to 8 or 10 per cent., and might already have been made, but the paper was not definite about that.

It was a pity, in view of the importance of the heat loss in the cooling water, that in no case were the actual temperatures of the water stated, although that was done both for the shaft temperatures and for the ground temperatures. Also, although the method of water measurement by means of a float had been checked to a certain extent, it would have been much more satisfactory if the float method had been tested against the V-notches where these were used.

It was true that, as Dr. Marshall said, all the cooling water was not used in the form of sprays, and hence was not all subject to evaporation. Nevertheless, the considerable importance of evaporation heat loss (about 1,000 B.th.u. per lb., whereas the sensible heat loss in the cooling water varied from 6 to 15 B.th.u. per lb., so that a very small proportion of evaporation might add greatly to the total heat loss) meant that until that point was settled, the estimates of cooling-water heat loss were quite imperfect and no conclusions could be based thereon.

In these circumstances it was certainly bold of Dr. Marshall to recommend the replacement of plate cooling by sprays.

AUTHOR'S REPLY.

In replying to the discussion Dr. MARSHALL wrote that Mr. Hacking's comments on the significance of the discrepancies between the results of the present tests and those previously recorded, and on the possibility of errors arising in computing thermal balance sheets, would be readily appreciated by those investigators who had attempted these tasks. To his mind one of the most important results of these tests was to indicate the urgent need for a wider application of research into the physical and chemical principles of blast-furnace operation.

Since the corresponding curves on the two diagrams comprising Fig. 7 followed similar contours, the curve relative to the second test at Plant *B* was omitted from the lower diagram to simplify it. In the upper diagram, the points on the Plant *B* curves were all displaced slightly to the right. The plotted figures are recorded in Table I.

The position of the zones of maximum lining wear on the shafts of the furnaces examined was probably closely related to the intimacy of mixture of the ingredients of the ores used.

Plants *A*, *B* and *D* used what might be termed self-fluxing ores, which tended by reason of the closer contact of the constituents to form silicates of iron and manganese earlier, that was, higher up the shaft than at Plant *C*, where a dense hematite was employed. The erosion of the lining by these initial slags rich in FeO and MnO, and the consequent zone of high temperature on the shaft, was correspondingly further from the tuyeres at Plants *A*, *B* and *D*. It seemed significant that the peaks of the shell-temperature diagrams were rather more sharply defined at these three plants, suggesting that the same intermixing of the ingredients facilitated the reduction of the FeO to iron and its replacement by CaO and MgO. These observations agreed with Mr. Hacking's suggestion of a delayed reduction of the dense hematite ores, giving at Plant *C* a much steeper temperature gradient from the tuyeres upwards.

It seemed probable that when a new furnace was blown in, the thickness of lining round the bosh area rapidly assumed a value dependent on the amount and the efficiency of the water-cooling employed. In a lesser degree, a similar state of affairs might exist in the lower regions of the shaft. A regular survey of the shaft temperatures of a furnace throughout its life might therefore give valuable information regarding the rate of wear and the most economical thickness to start with. In any event, taking periodic shaft temperatures would lead to an early discovery of weak spots, with the possibility of extending the life of the lining.

Mr. Bailey's suggestion that there had to be a margin between the actual external heat losses and the fuel consumed in a furnace to make good these losses was undoubtedly correct. Mr. Bailey's value of " from 3 to 5 times " for this margin was unsatisfactory for two reasons. First, its wide range offered ample scope for error in thermal computations. Secondly, it had been based on a study of reheating furnaces, which were not affected by the complex transfer of thermal energy between the shaft and hearth obtaining at a blast-furnace. Until the chemical and thermal reactions proceeding in a blast-furnace had been investigated more thoroughly this margin must remain an estimate. The present work could be regarded as one stage in such an investigation. Until more such data had been obtained, it was impossible to solve the problem propounded by Mr. Tucker.

Mr. Webber's criticism that the evaporation losses had been neglected was justifiable, but the author thought that Mr. Webber had considerably over-estimated their magnitude. In the first place, from figures available at three plants, the average amount of cooling-water used on sprays, and therefore subject to evaporation, was found to be only 15 per cent. of the total, the remainder being used in a closed system. Secondly, the construction of

three of the test furnaces was such that the upward movement of air necessary for unlimited circulation was greatly restricted by platforms fitting closely to the furnace. From personal experiences the author would suggest that, under average weather conditions, the atmosphere in these zones did not depart materially from still-air conditions. The heat loss by the evaporation of cooling water from the bosh at plant *D* had been calculated, using a formula as follows:

$$\text{Rate of evaporation of water} = \left(\frac{(\text{vapour pressure of water}) - (\text{vapour pressure of water vapour in air})}{50}\right)^{1\cdot2}$$

in kg. per sq. m. per hr.

For this furnace the loss was found to be 104 B.th.u. per sq. ft. per hr. Since similar conditions obtained on the other furnaces, this figure was used in calculating the heat loss in the evaporation of cooling-water on the other furnaces. The results are given in Table A.

TABLE A.

Plant.	Bosh Area. Sq. ft.	Hearth Area. Sq. ft.	Total Evaporation. Heat Loss B.th.u. per hour.	Total Heat Loss previously recorded. B.th.u. per hr.	Ratio of Evaporation Loss to Total Heat Loss.
A	605	not spray-cooled.	63,000	4,862,000	0·0129
B	565	Ditto.	59,000	4,730,000 (Av.)	0·0125
C	840	594	149,000	6,167,000	0·0241
D	694	640	139,000	7,928,000	0·0175

The formula used applied to still-air conditions and had been checked experimentally by several independent observers.

In calculating the heat loss by radiation and convection from the shaft, each furnace was divided into convenient units represented by the bands of plates, the results for each band being calculated separately. Mr. Webber's suggested correction for the fact that the hottest belts were those largest in diameter had already been made.

It would be impossible without unduly lengthening the paper to give the water temperatures suggested by Mr. Webber. For two furnaces the heat loss in the cooling-water was not measured on the water as a whole, but in a large number of small sections, as was indicated in the description of the methods employed. To give some idea, however, the inlet water temperatures ranged from 75° to 85° F., and the outlet water temperatures (the entire furnace cooling-water) from 85° to 100° F.

AN INVESTIGATION INTO THE OXIDISING POWER OF BASIC SLAGS.*

PART I.—THE DETERMINATION OF THE BINARY DIAGRAM CaO–Fe_2O_3.

PART II.—THE DETERMINATION OF THE DISSOCIATION PRESSURES OF Fe_2O_3, CaO.Fe_2O_3 AND 2CaO.Fe_2O_3.

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Summary.

In the binary system Fe_2O_3–CaO, evidence of the existence of two compounds only, monocalcium ferrite and dicalcium ferrite, has been obtained. The more important optical properties of these compounds have been ascertained. At the Fe_2O_3 end of the system the diagram is really of a pseudo-binary nature, due to the dissociation of the excess Fe_2O_3 at high temperatures. The melting point of Fe_2O_3 was determined as 1,595° C., but this figure is low, due to the presence of ferrous iron resulting from the dissociation of the ferric oxide. The dissociation pressure of Fe_2O_3 was investigated; it was found to be appreciable at 1,100° C., and to increase rapidly with the temperature, reaching a pressure of the order of 5×10^5 atm. at its melting point. Evidence has been obtained which indicates that Fe_2O_4 is partially soluble in Fe_2O_3, and that Fe_2O_3 is partially soluble in Fe_3O_4. From the available data a diagram for the system Fe_2O_3–Fe_3O_4 has been constructed.

The dissociation of monocalcium ferrite and dicalcium ferrite has been investigated. Below the peritectic temperatures of these compounds the oxygen pressure is infinitesimal; at higher temperatures the pressure would seem to be due to the dissociation of the Fe_2O_3 resulting from the peritectic reactions. The oxygen pressure of the ferrites falls rapidly as the FeO increases. CaO has a marked stabilising effect upon Fe_2O_3.

In recent years much attention has been given to the functions of the slag in the refining operations in the open-hearth process of steel production. Much of the data and also the theoretical treatment of the subject are recorded in the report of the Symposium on the Physical Chemistry of Steel-Making Processes held by the Faraday Society in June, 1925. McCance[1] has recently reviewed the work in this field and has shown that whilst the behaviour of the slag/metal relationships in the acid process can be accounted for in a reasonably satisfactory manner on theoretical grounds, the same cannot be said for the basic process. In the latter process one of the outstanding anomalies is the rapid accumulation of FeO in the finishing slags.

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In discussing this phenomenon McCance states that he believes that Fe_2O_3 plays an important part owing to the formation of calcium ferrites. Their presence in basic slags has been observed by Ferguson.[2] McCance assumes that in the early stages of the boil, when much carbon is present in the bath, the calcium ferrite compounds will be reduced by the carbon, resulting in FeO, which will again become oxidised to recombine with lime to form calcium ferrites. Thus the FeO will act as an oxygen carrier. However, towards the end of the boil the iron becomes the reducing agent, so resulting in an accumulation of FeO in the system. Ferguson[2] discusses the building up of FeO in the slag, and assumes that it arises from the reduction of ferric oxide by iron, the FeO so formed being again oxidised to ferric oxide. He believes, however, that the addition of lime to the slag checks its oxidising power and so serves as a means of control in basic refining practice. Reagan[3] discusses the control of FeO in basic furnace slags and gives curves showing the increase in FeO towards the end of the operation. He suggests that the SiO_2 content of the slag is the most effective means of controlling the FeO content of the slag, although, according to Ferguson, if the addition of SiO_2 is excessive then oxidised and dirty steel is the result.

Before commencing to study actual furnace slags it was considered desirable to know something of the behaviour and properties of the constituents which are usually found in such slags. Data for many of the systems, such as FeO–MnO, FeO–SiO_2, MnO–SiO_2, CaO–SiO_2, CaO–FeO–SiO_2, were already available. The system CaO–Fe_2O_3 had been examined by many workers, the most recent work on the subject being that of Sosman and Merwin.[4] The results of these investigators differed from those of the earlier workers in that the former showed evidence of the existence of only two compounds, namely, mono- and di-calcium ferrite, instead of three or more compounds. The earlier literature always made reference to tricalcium ferrite, whilst some workers cited as many as five compounds. Ferguson[2] gave evidence for the existence of tricalcium ferrite.

The Fe_2O_3-rich portion of this system had always presented difficulty, and was not on a satisfactory basis. Consequently, in addition to collecting data on the properties of the various ferrites, it was felt desirable to redetermine the thermal diagram for this system.

PART I.—*The Determination of the Binary Diagram CaO–Fe_2O_3.*

Preparation of Fe_2O_3.—The most satisfactory source of pure Fe_2O_3 was found to be the decomposition of pure ferrous oxalate under correct conditions. Ferrous oxalate was heated

in an alundum boat at a slow rate in an evacuated tube. The decomposition was carried out at the lowest possible temperature to ensure the production of the highly reactive form of FeO—the so-called pyrophoric form. During the process of decomposition the gases were continuously removed from the furnace by a Cenco-Hyvac pump. When decomposition was complete—indicated by the cessation of the liberation of gas—the furnace was cooled to 400° C. and oxygen admitted. Vigorous oxidation of the FeO to Fe_2O_3 occurred, accompanied by the evolution of heat. This was frequently sufficient to raise the temperature of the mass by 200° C. Should the temperature of the mass before the admission of the oxygen have been too high then a sintered mass containing much FeO was produced. Each batch of Fe_2O_3 was tested for ferrous iron by a colorimetric method employing an ammoniacal solution of dimethylglyoxime. The colour of Fe_2O_3 varies considerably and depends upon the temperature during oxidation. Sometimes there was a marked variation of colour in the same batch, indicating a temperature gradient over the length of the boat. The colour generally varied from reddish-brown to a slate colour. On one occasion the product was orange in colour and was strongly magnetic, though the presence of ferrous iron could not be detected. This material was more readily soluble in hydrochloric acid than the usual product and was undoubtedly the low-temperature modification of Fe_2O_3 mentioned in the literature.

Preparation of CaO.—CaO was prepared from pure calcium oxalate by decomposing it in a platinum basin at a temperature of 1,000° C. The product was tested before use to ensure the absence of CO_2.

Experimental Procedure.—The furnace employed for the determination of the thermal data consisted of an alundum tube wound with molybdenum wire and enclosed in a suitable steel case. The furnace was made sufficiently large to carry a Pythagoras tube, 2 in. in diam. This tube was placed in the furnace in a vertical position and the lower end, which was within the furnace, was closed. The upper end carried a rubber bung, thrqugh which passed the thermocouple wires and also a glass tube to allow of evacuation, and of the admission of a suitable gas if required. The length of the Pythagoras tube was 3 ft., and consequently the top end was never hot enough to damage the rubber bung.

A platinum crucible and a platinum/platinum-rhodium thermocouple were employed. The couple was standardised from time to time. The differential and the inverse-rate methods of recording heating and cooling curves were employed, although the former was generally found to give the better results. In the early experiments difficulty was experienced with the thermo-

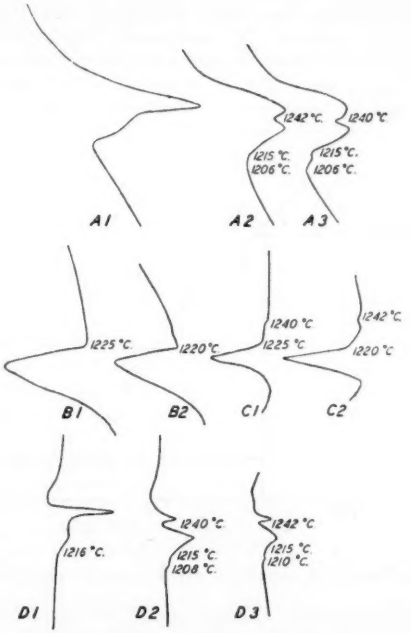
couple when the hot junction was inserted into the melt in the crucible ; one of the chief causes of trouble was the great tendency of many of the melts to creep up the couple wires ; on occasions, the melts would creep a distance of 1 in. or more. Finally, the thermocouple point was attached to the outside of the crucible, this having been proved to be satisfactory from all standpoints.

The various melts were prepared by grinding together in an agate mortar the requisite amounts of CaO and Fe_2O_3 and transferring the mixture to the platinum crucible. Chemical analysis was made of each melt after the determination of the thermal data, and in all cases satisfactory agreement with the original mixture was obtained. The melts were also examined for the presence of ferrous iron, and, except in the case of a few melts very rich in Fe_2O_3, to which reference will be made later, it was found to be absent. Finally, the optical properties of the phases present in each melt were determined. For this purpose the melts were crushed to a fine powder and the refractive index was measured by the Becke method, using, in the case of phases with a refractive index above 1·78, the immersion medium of Merwin and Larsen,[5] consisting of sulphur and selenium in the form of a glass. By varying the proportions of sulphur and selenium a series of such glasses was made having refractive indices ranging from 1·98 to 2·92.

Discussion of Results.—Fig. 1 shows the inverse-rate and also the differential heating and cooling curves for monocalcium ferrite, inverse-rate and differential curves being taken simultaneously. All other thermal curves are of a similar type and therefore only the one set need be given here. The thermal determinations were made in oxygen under a pressure of 1½ atm. This pressure, however, was not sufficient to prevent dissociation from occurring in those melts containing a large excess of the Fe_2O_3 phase. From the data obtained from the dissociation pressure determinations it was realised that it would not be possible to determine the melting point of Fe_2O_3 under a pressure sufficiently great to prevent dissociation. From the extrapolation of the dissociation curve of Fe_2O_3 it is found that in the neighbourhood of the melting temperature the pressure is of the order of 5×10^5 atm. Before the dissociation pressures had been determined the reason for the absorption and evolution of heat in what was known to be the liquid state of melts high in Fe_2O_3 was obscure. By heating to just below this temperature and cooling, it had been proved that the mass had been melted. However, the dissociation curves showed that this heat absorption at a temperature above the liquidus is due to the dissociation of Fe_2O_3, the change occurring in the dissociation experiments when under a pressure of 1½ atm. at exactly the same temperature as in the thermal curves. It is therefore highly probable that the melting

points recorded for Fe_2O_3 and for Fe_2O_3-rich melts are low, and that this portion of the diagram is really of a pseudo-binary nature.

It was observed that if CaO and Fe_2O_3 in the proportions required to form $CaO.Fe_2O_3$ were heated together to 1,250° C.



A. Differential Curves on Heating.
B. Differential Curves on Cooling.
C. Inverse Rate Curves on Cooling.
D. Inverse Rate Curves on Heating.
(Curves *A*1 and *D*1 are initial heating curves.)

FIG. 1.—Heating and Cooling Curves of Melt containing 25·9% CaO and 74·1% Fe_2O_3 (monocalcium ferrite).

in air, no compound was formed. This is due to the decomposition of Fe_2O_3. If, however, the mixture was heated to 1,000° C. in air and maintained at this temperature for several hours, it was converted into a dark powder in which no free CaO could be detected. On heating this powder to 1,250° C. it was found that melting had occurred, and, on cooling, a mass of hard, black, metallic-looking needles was obtained. It was found that all

melts in excess of $2CaO.Fe_2O_3$ contained free lime as a phase. Owing to the high temperatures necessary, and the lack of refractory materials to withstand pressure at these high temperatures, no melts in excess of 50 per cent. CaO were made.

Fig. 2 shows the thermal data plotted in the form of a binary diagram. Evidence for the two compounds, monocalcium ferrite and dicalcium ferrite, has been obtained, and this has been

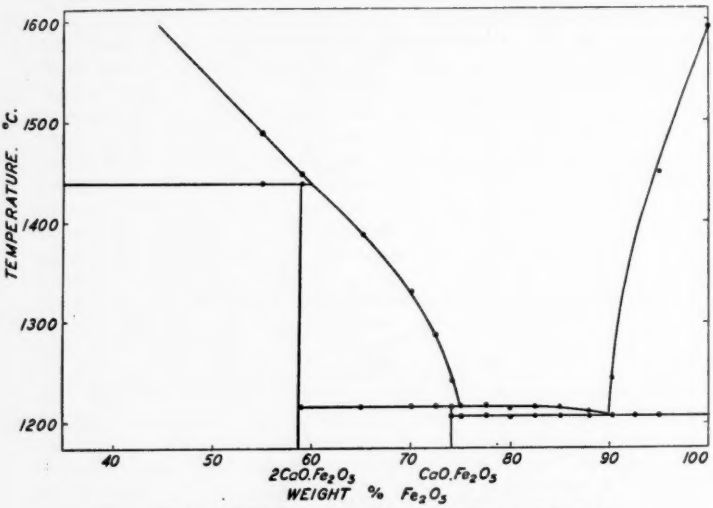


FIG. 2.—Thermal Equilibrium Diagram of the System $CaO–Fe_2O_3$.

supported by the optical examination. There is no evidence which points to the existence of tricalcium ferrite or higher compounds.

The optical properties of the various phases were as follows :

Fe_2O_3. Refractive index : greater than 2·95, less than 3·10.
Colour : deep red ; slightly pleochroic.
Straight extinction ; appears to be uniaxial, negative.

$CaO.Fe_2O_3$. Refractive index : between 2·5 and 2·6.
Colour : reddish-brown ; brown in thin sections ; pleochroic.
High polarisation colours ; straight extinction ; appears to be uniaxial.
Melt was made up of dark needles, having a metallic lustre. They were very hard, but could be scratched with a knife.

$2CaO.Fe_2O_3$. Refractive index : between 2·3 and 2·36.
Colour : light brown ; decidedly pleochroic.
Nearly straight extinction ; appears to be biaxial.
Melt was tabular in appearance and not so hard as the monocalcium compound.

PART II.—*The Determination of the Dissociation Pressures of Fe_2O_3, $CaO.Fe_2O_3$ and $2CaO.Fe_2O_3$.*

The dissociation of Fe_2O_3 at high temperatures has been investigated by several workers. Probably the most important contributions have been those of Walden[7] and of Sosman and Hostetter.[8]

Walden obtained his results by heating Fe_2O_3 in a sealed tube and measuring the pressures developed at different temperatures. He assumed that Fe_2O_3, in the pure state, would have a definite dissociation pressure dependent on the temperature alone. Sosman and Hostetter claimed that this was not the case, and that the pressure at any temperature was also a function of the amount of ferrous iron which had been formed through dissociation. They published curves in which the dissociation pressure was plotted against the composition at constant temperature; these they interpreted as showing a complete range of solid solutions between the compositions Fe_2O_3 and Fe_3O_4. This has since been pointed out to be highly improbable in the light of thermal data and microscopic evidence.[6] One point of importance emerged from the work of Sosman and Hostetter, namely, that the initial dissociation of Fe_2O_3 was much higher than had previously been supposed, and their figure is more in keeping with that observed by various workers for the temperature at which the dissociation of Fe_2O_3 begins in air.

Details of Apparatus.—Several attempts were made to construct an apparatus suitable for this work. One of the chief difficulties encountered was to find a tube capable of maintaining a vacuum at temperatures above 1,200° C. and yet of suitably small volume. Porcelain, fused silica and small-diameter Pythagoras tubes were all tried without success. Finally it was decided to have recourse to the larger size of Pythagoras tube used in the earlier section of the work, and to overcome the disadvantage of the large volume by using larger quantities of the material.

A specially designed, horizontal, molybdenum-wound furnace, large enough to take the Pythagoras tube, was used. The tube was closed at one end, and the other end carried a rubber bung, through which passed connections to the mercury pressure gauge and to the Cenco-Hyvac pump, and also the thermocouple wires. Special precautions were taken to prevent heat from reaching the rubber bung, baffles and a water-cooled copper coil being used for this purpose. A vernier cathetometer, capable of reading to 0·0001 cm., was employed to read the mercury levels in the pressure gauge. Between the pump and the furnace tube was inserted a T-piece, one leg of which was connected to a conical pressure flask and thence to an oxygen cylinder. The glass flask was also connected to a second pressure gauge, so that, if

necessary, known volumes of oxygen could be added to, or withdrawn from, the system, stopcocks being provided for this purpose.

Experimental Procedure: Fe_2O_3.—Blank experiments were run to test the apparatus. Then a series of preliminary experiments was carried out on Fe_2O_3, which had been prepared in a similar manner to that already described. In these experiments the oxide was spread in a thin layer in a platinum boat, but this method had to be abandoned because it was found that the dissociation did not proceed uniformly over the whole surface. This may have arisen because of the existence of a slight temperature gradient along the length of the boat, causing dissociation to commence at one point and to proceed in a step-like fashion. This occurrence was brought prominently to notice in one experiment in which the rate of cooling had been abnormally quick. The resultant material was found to be magnetic and apparently consisted largely of Fe_3O_4 at one end, whilst at the other end it was entirely Fe_2O_3. It was also found that the use of thick layers of the material did not materially affect the uniformity of the mass, indicating that the charge remained sufficiently porous to admit oxygen to all parts on cooling. A platinum crucible was therefore substituted for the boat, so that the charge might be concentrated as much as possible about a single point in the furnace. This resulted in close agreement between different runs.

The method finally adopted was to start heating the charge under a known pressure of oxygen in the tube. In the course of the heating the temperature was held steady at suitable intervals till a state of equilibrium had been attained, the value of the pressure being read off by means of the gauge. As the temperature increased, the pressure rose till a temperature was reached at which the dissociation pressure of the oxide was greater than that existing in the tube. A more rapid increase of the pressure with the temperature then took place, this being shown by a break in the pressure/temperature curve. By varying the initial oxygen pressure the temperature at which this break took place could be altered. After a run the pressure in almost all cases returned to practically the same value as had been initially employed. The temperature of the room was recorded each morning, when the final pressure from the previous day's run, as well as the initial pressure adopted for the next run, was measured. During the whole series of experiments this did not vary more than 3° C. In the case of runs in which the initial pressure was less than 0·5 cm. of mercury, small increases in pressure occurred on heating, due apparently to the evolution of adsorbed gases from the tube. These evolutions were irreversible, as the gas was not picked up again on cooling, and the

final pressure at room temperature was invariably higher than the initial pressure before heating. A slight degree of hysteresis in the equilibrium $Fe_2O_3 \rightleftarrows Fe_3O_4$ + oxygen at low oxygen pressures is also a possible explanation. For this reason the values obtained for the dissociation pressures using very low initial pressures are, in all probability, slightly high (see later).

Being assured that the apparatus was capable of yielding results of the degree of accuracy required, a series of experiments was carried out to find the time required to attain equilibrium. By means of the furnace control adopted, together with the use of a highly sensitive galvanometer and Tinsley vernier potentiometer for temperature measurement, it was possible to maintain the temperature constant within 1° C. as long as desired. It was found that the system attained equilibrium, both on heating and cooling, with a considerable degree of rapidity, particularly at temperatures over 1,200° C. For actual determinations, from half-an-hour to one hour was allowed at each stage. In order to determine the dissociation temperatures under different oxygen pressures, the initial pressures were varied as already described. From the preliminary experiments, the following points emerged :

(1) When freshly prepared oxide was used a large irreversible evolution of gas took place at comparatively low temperatures. This was absent on subsequent heatings, and was, no doubt, due to the presence of much gas in the finely-divided oxide when freshly prepared.

(2) At temperatures from 1,100° C. and upwards, depending on the initial pressure in the tube, the pressure began to increase more rapidly with temperature, and continued to do so at an increasing rate as the temperature was still further raised. This evolution of gas was strictly reversible on cooling. It was also observed that, when a small amount of oxide was used, or where the initial pressure was very low, at still higher temperatures there was again a lowering of the rate at which the pressure increased with the temperature.

(3) When the results were plotted on a pressure/temperature diagram, it was found that the steep parts of all the curves tended to one limiting curve.

A number of temperature/pressure curves have been plotted in Fig. 3. Over forty different curves were determined. It will be observed that all converge on the same limiting curve. The upper temperature to which these curves could be taken was limited in all cases by the tendency of the Pythagoras tubes to collapse at high temperatures. The maximum pressure that was considered safe to employ at high temperatures was about $1\frac{1}{2}$ atm.

The following interpretation of these results is given : The first uniform portion of all the curves results from the increase in temperature of the gas already enclosed in the tube, causing an increase in pressure according to the gas laws. The pressure of oxygen in the tube in this region is presumably greater than the dissociation pressure of the oxide, so that no dissociation takes

place. As the temperature is increased, a point is reached at which the dissociation pressure becomes greater than the oxygen pressure in the tube, and an evolution of oxygen accordingly takes place, accompanied by a corresponding rise in pressure. There is therefore an increase in the rate at which the pressure increases with the temperature. This is at first gradual, but later increases more rapidly, as shown by the curves. Thus the pressure/temperature curves show two distinct parts in this

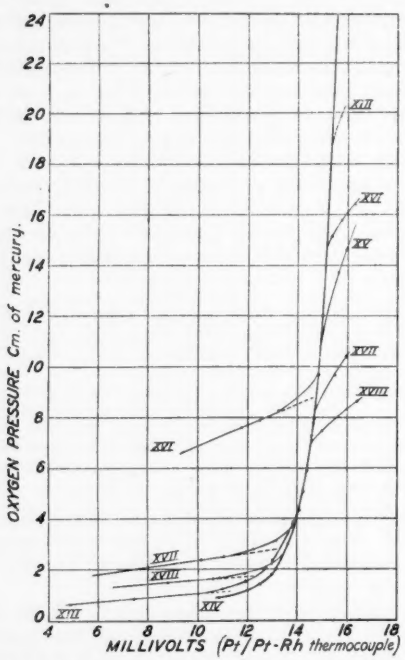


FIG. 3.—Examples of Pressure/Temperature Curves with Fe_2O_3 in the Tube, showing their relationship to a common envelope curve. (Roman numerals are reference numbers of the experiments.)

region : (1) A curved portion where the *rate* of pressure increase is increasing fairly rapidly ; and (2) a very steep portion where the *pressure* increases very rapidly. On some of the curves a third part is shown where the *rate* of increase again falls off. The steep parts of all the curves can be imposed on the same envelope curve, and apparently indicate the existence of a definite phase, whose dissociation pressure is dependent only on the

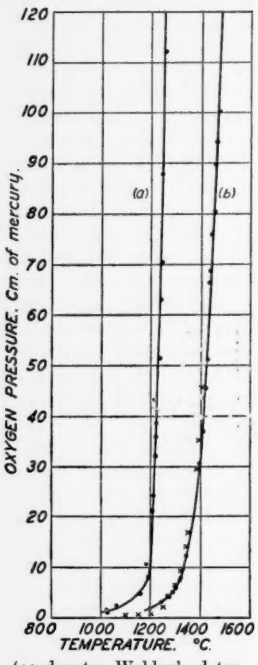
temperature, and is independent of the amount present. This phase cannot be pure Fe_2O_3, as a considerable amount of oxygen has already been evolved, as shown by the preceding portion of the curve. Further, in this latter portion, the pressure/temperature values are peculiar to the individual curves on which they appear, and the value of the pressure at any point appears to depend on the amount of dissociation which has already taken place in the oxide. In other words, it would appear that the pressure in this region is a function of the composition of the solid as well as of temperature. Hence it would seem that the substance formed on the liberation of the first portion of the oxygen from the Fe_2O_3 must be soluble in the remaining Fe_2O_3. Finally, when the limit of solubility has been reached, a phase of definite composition exists, any further dissociation being accompanied by the formation of a new phase. The first phase can be regarded as a solution of Fe_3O_4 in Fe_2O_3, the second being Fe_2O_3 in Fe_3O_4. The complete dissociation of the Fe_2O_3-rich phase would result in a marked deviation from the common envelope curve, and this is shown in those curves for which the conditions were suitable for this degree of dissociation to be attained. The curve showing the initial dissociation pressure against the temperature, and also the envelope curve (or dissociation-pressure curve of the saturated solution of Fe_3O_4 in Fe_2O_3) are shown in Fig. 4. The experimental points on the former are those values on the individual curves at which oxygen evolution first became apparent, as shown by the change in the curvature; those on the latter are points lying on the steep portion of the individual curves.

On this diagram are also shown the values which were experimentally determined by Walden[7] and published as the dissociation pressures of ferric oxide. It is observed that these values are in very good agreement with the curve here given for the dissociation of the limiting solid solution of Fe_3O_4 in Fe_2O_3. Consideration of the method employed by Walden indicates that it is highly probable that the pressures which he measured were those of the limiting solid solution, and therefore his work provides confirmation of the present results.

The experimental values have also been plotted in the form of the logarithm of the pressure against the reciprocal of the absolute temperature, Fig. 5, curve (*a*) being that of the initial dissociation, and curve (*b*) that of the limiting solution. Both curves appear to be linear, except that the four lowest values (representing pressures of less than 5 cm. of mercury) are apparently too high. The fact that their deviations are also linear is suggestive of some physical meaning, but, as previously mentioned, these very low values are not above suspicion, owing to gas evolution from the tube. Further experimental work with apparatus suitably designed for the measurement of very low

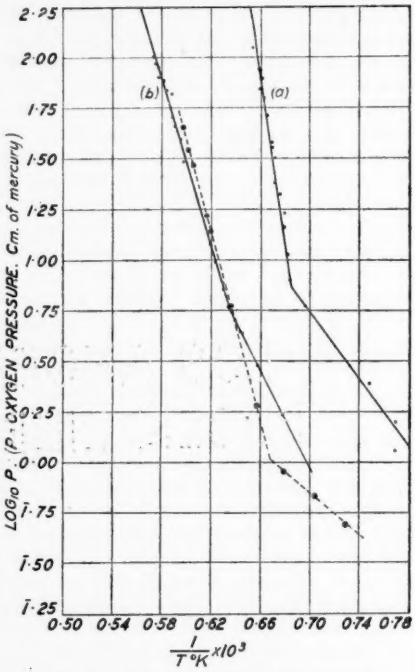
pressures would be required before any conclusions could be drawn regarding this portion of the curves. Walden's values are also plotted on this diagram, and again this marked deviation is to be observed, although occurring at a somewhat lower pressure than in the curves derived from the present experiments.

A series of pressure/composition isotherms was constructed from the pressure/temperature curves. The method adopted was



(× denotes Walden's determinations.)

FIG. 4.—Dissociation Pressures.



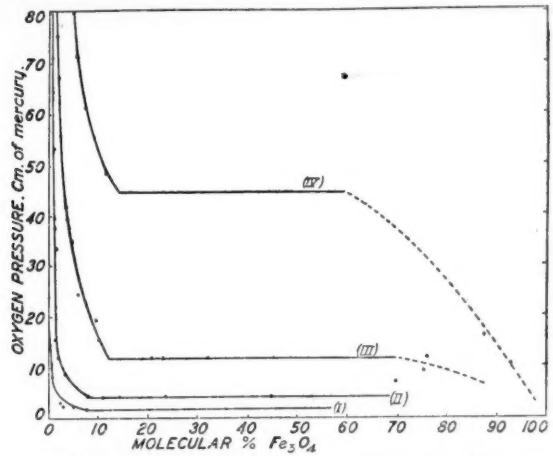
(Broken line indicates Walden's results.)

FIG. 5.—Dissociation Pressures ; logarithm of the pressure plotted against the reciprocal of the absolute temperature.

(*a*) Initial Dissociation Pressure of Fe_2O_3.
(*b*) Dissociation Pressure of Saturated Solution of Fe_3O_4 in Fe_2O_3.

to calculate, from a consideration of all the available curves, an " expansion factor " for the gas in the tube from room temperature to the isothermal temperature selected. This was rendered necessary by the temperature variation of the system. The agree-

ment between the various curves—about forty in all—was very satisfactory. An exception must be made in the case of those curves obtained when using very low initial pressures; as already stated, there was evidence of irreversible gas evolution in these cases. A check on the value of the "expansion factor" was obtained by running blank experiments with oxygen in the system. A value for the volume of the apparatus was obtained by measuring the pressure in the tube before and after the addition of a known volume of oxygen to the system. It was then possible to calculate the weight of oxygen liberated from the oxide for any temperature

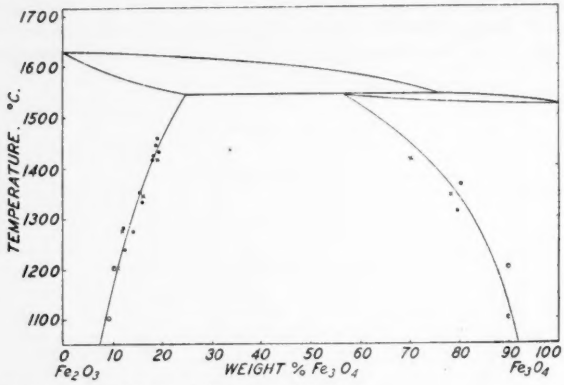


(I.) At 1,200° C. (III.) At 1,345° C.
(II.) At 1,272° C. (IV.) At 1,415° C.

FIG. 6.—Dissociation-Pressure/Composition Isotherms for the System Fe_2O_3–Fe_3O_4.

and pressure on the curves. For this purpose the initial part of the curves was produced in each case to enable the pressure increase, due to dissociation, to be obtained. This procedure was made possible by the fact that over the range of temperature concerned, 1,100° C. to 1,500° C., the pressure increase with temperature approached very closely to linearity. The proportion of ferrous iron present in the solid phase could then be calculated for various temperatures and pressures. Further details of the procedure adopted in these calculations are given in an Appendix. Fig. 6 shows the pressure/composition isotherms for the temperatures 1,200° C., 1,272° C., 1,345° C. and 1,415° C. Whilst the absolute accuracy of these results depends upon the accuracy with which the "expansion factor" has been determined, the

relative agreement of the points on the isotherms is independent of this factor. The close agreement of these points can therefore be taken as a proof of the validity of the procedure. Fig. 7 shows the data derived from the isotherms plotted on the qualitative phase diagram given by Benedicks and Löfquist[6] for the system Fe_2O_3–Fe_3O_4. Additional points calculated from the individual pressure/temperature curves are also shown, together with values



× Points obtained from isotherms of Fig. 6.
• Points obtained from individual pressure/temperature curves by calculation.
∘ Approximate indications from the isotherms of Sosman and Hostetter.
(Melting ranges are qualitative only, as given by Benedicks and Löfquist.)

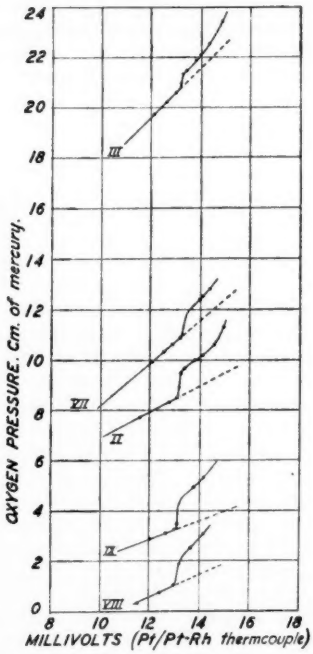
FIG. 7.—Thermal Equilibrium Diagram of the System Fe_2O_3–Fe_3O_4.

obtained from the work of Sosman and Hostetter,[8] assuming that the central portion of their curves should be horizontal.

The calculation of the heat of reaction, Q, for the equation $6\,Fe_2O_3 \rightleftarrows 4\,Fe_3O_4 + O_2$ from experimentally determined dissociation pressures has always resulted in values much lower than those obtained by direct measurement. The partial mutual solubility of these oxides would appear to be a probable cause for this disagreement, and calculation from the data available has indicated that a higher value of Q should be obtained.

Monocalcium Ferrite.—At an early stage in the work on this compound it was evident that conditions similar to those for ferric oxide applied to its dissociation, namely, that the pressure developed was a function of the composition as well as of the temperature. The same technique was therefore employed to determine the dissociation of $CaO.Fe_2O_3$ as had been devised for Fe_2O_3. At first the monocalcium ferrite was prepared in a separate operation, but latterly the requisite quantities of CaO and Fe_2O_3 were mixed together, put into a platinum crucible, and heated

to a suitable temperature under a pressure of 1½ atm. of oxygen. On cooling, the material was ready for investigation. Some of the results are shown in graphical form in Fig. 8. On heating the material *in vacuo* it was found that no change took place until the incongruent melting point was reached (Fig. 2). At this temperature a sudden increase in pressure took place, shown by a definite step in the pressure/temperature curve. The pressure obtained after this gas evolution was not, of course, the equilibrium pressure of the compound, the pressure being limited by the amount of ferric iron available for dissociation, and also by the large volume of the tube. Runs were therefore made with increasing



Weights of $CaO.Fe_2O_3$ involved: Curve VIII., 7·25 grm.; Curves II., III., VII., IX., 10 grm.

FIG. 8.—Examples of Pressure/Temperature Curves obtained with $CaO.Fe_2O_3$ in the tube.

(Roman numerals are reference numbers of the experiments.)

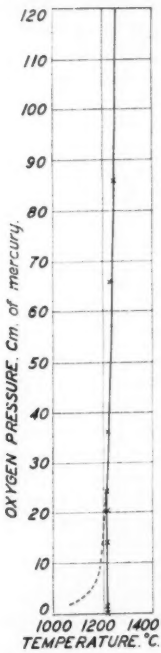


FIG. 9. — Probable Dissociation-Pressure/Temperature Curve for $CaO.Fe_2O_3$.

(Broken line indicates curve of initial dissociation of Fe_2O_3 as shown in Fig. 4.)

initial pressures of oxygen, till a pressure was reached when the break in the curve was displaced to a higher temperature. This appears to occur, as nearly as could be determined, at a pressure of approximately 24 cm. of mercury. This is therefore taken as the dissociation pressure of $CaO.Fe_2O_3$ at the temperature at which it undergoes the peritectic transformation into $2CaO.Fe_2O_3$ and Fe_2O_3. For higher oxygen pressures the break in the curve appears to be displaced to higher temperatures, though the rate of temperature rise with pressure is so small that it is difficult to determine exactly.

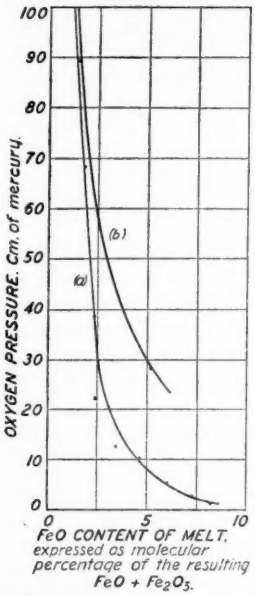
The temperature/dissociation-pressure curve obtained from these breaks in the individual curves is shown in Fig. 9. The upper portion of this curve probably coincides with the curve of the initial dissociation pressure of pure Fe_2O_3. This would appear to verify the peritectic dissociation indicated by the thermal phase diagram, the pressure recorded being due to the dissociation of free Fe_2O_3 liberated at the peritectic. It was further observed that, for a given temperature above the peritectic, the amount of oxygen liberated, as shown by the size of the " step " on the curve, decreased as the total oxygen pressure increased, indicating that the amount of dissociation depends on the oxygen pressure over the liquid melt. It was demonstrated by very slow rates of cooling that the change was reversible, although with some difficulty, only a portion of the liberated oxygen generally being picked up. From a consideration of Fig. 9 it is clear that under low oxygen pressures no pick-up of oxygen can occur until the actual freezing temperature is reached. Hence oxidation and freezing must be proceeding simultaneously, thus increasing the difficulty of oxygen pick-up.

In this connection a complication arose which would tend to make the apparent dissociation too great. In order to obtain as nearly 100 per cent. $CaO.Fe_2O_3$ as possible for these experiments, the molten material was always allowed to freeze as slowly as possible under a pressure of approximately 1½ atm. of oxygen. It was discovered that, in freezing, oxygen was very often entrapped within the melt. This oxygen was then liberated during the next heating under reduced pressure, and resulted in a slow rise of pressure below the melting point, or, when it could not be detected, as an increased oxygen evolution on melting. This fact was only realised when the bottom of one of the platinum crucibles was " ballooned out " owing to the internal pressure. For this reason a boat was used for some of the later determinations.

From the individual pressure/temperature curves shown in Fig. 8 it was possible, as in the case of the experiments on ferric oxide, to measure the amounts of oxygen evolved by the various melts at a temperature of 1,272° C., and hence by calculation to find the amount of ferrous iron formed in each case before

equilibrium was attained. The dissociation pressure was found to be a decreasing function of the ferrous iron content.

Further, when melts were run with a greater proportion of Fe_2O_3 than that required by the composition $CaO.Fe_2O_3$, dissociation began at a lower temperature owing to the free Fe_2O_3, and, in addition, an increased amount of dissociation was obtained for a given equilibrium pressure at 1,272° C. Moreover, this increase could not be accounted for quantitatively by the dissociation of the added Fe_2O_3 as such. It is apparent, therefore, that the amount of lime is also a factor in the equilibrium in addition to the temperature and the oxygen pressure. For the purposes of graphical representation, the FeO formed in the melt was expressed as a molecular percentage of the total $FeO + Fe_2O_3$, for a given initial ratio of CaO to Fe_2O_3, the change in the ratio due to the oxygen evolution having been shown to be so small as to be negligible. The results are graphed in Fig. 10, curve (*a*)



Initial Molecular Ratio CaO/Fe_2O_3: (*a*) 1 : 1. (*b*) 1 : 1·67.

FIG. 10.—Dissociation - Pressure/Composition Curves at 1,272° C. of $CaO–Fe_2O_3$ Melts.

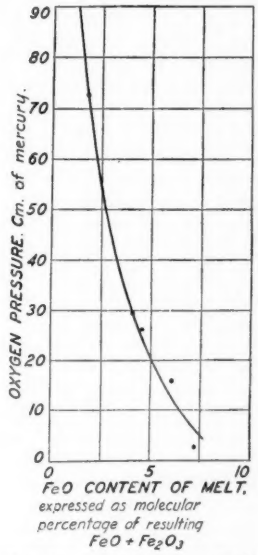


FIG. 11.—Dissociation - Pressure/Composition Curve at 1,485° C. of Melt of initial composition $2CaO.Fe_2O_3$.

showing the equilibrium conditions in melts of the original composition $CaO.Fe_2O_3$, and curve (*b*) in melts in which the Fe_2O_3 was originally in excess of the lime in the molecular ratio of 1·67 : 1.

Dicalcium Ferrite.—The determination of the dissociation pressure of this compound was rendered difficult by the inability of the tubes to stand up to the higher temperatures involved when the pressures inside were much below atmospheric pressure. It was possible, however, to heat the compound *in vacuo*, to temperatures in excess of the peritectic temperature of the monocalcium compound, and no rise of pressure was apparent. A run was also made with oxygen at a pressure of over one atmosphere. A distinct " step " was obtained at 1,436° C., the temperature of the peritectic transformation of the dicalcium compound. Further, when a similar pressure of nitrogen was used, a similar but much larger " step " was obtained at the same temperature. The same considerations, therefore, seem to apply to this compound as to the monocalcium compound, the rise in pressure being probably due to the dissociation of Fe_2O_3 liberated by the peritectic reaction.

A series of runs was carried out with varying amounts of nitrogen and oxygen. The curves obtained are very similar in form to those for the monocalcium compound, with this difference, that the " step " takes place at 1,436° C. The curves have therefore not been reproduced. With the apparatus available it was impossible to displace the initial oxygen evolution to a higher temperature. The reason is obvious from a consideration of the dissociation pressure curve for pure Fe_2O_3 ; a pressure of the order of many thousands of atmospheres would be necessary. However, by the methods already described, the molecular percentage of FeO reckoned against the total $FeO + Fe_2O_3$ was again calculated for the various melts, this time at a temperature of 1,485° C. ; the results are plotted against the oxygen pressures in the tube in Fig. 11 ; the curve is similar in form to that obtained in the case of $CaO.Fe_2O_3$ at 1,272° C.

Consideration of Curves.—From a consideration of Figs. 9 and 10 it is seen that although the initial dissociation pressure of $CaO.Fe_2O_3$ is probably the same as that of pure Fe_2O_3, the conditions of equilibrium in regard to the proportion of ferrous iron to ferric iron are very different. The amount of initial dissociation in the ferrite melts at 1,272° C. is actually greater than in free Fe_2O_3 at this temperature for pressures above 5 cm. of mercury (see isotherm at 1,272° C. of Fig. 6). This is also obvious on comparing the curves in Fig. 3 with those in Fig. 8. In the latter case a distinct step is apparent as soon as dissociation begins. In the one case the pressure recorded is that of a solution of Fe_3O_4 in Fe_2O_3 in the solid state ; in the other, the material is molten at 1,272° C., and the amount of dissociation is considerably

greater that that of the Fe_2O_3–Fe_3O_4 solid solution at the same temperature. However, after this initial dissociation, the remaining ferrite is much more stable than Fe_2O_3 under similar conditions, as shown, first, by comparing the shapes of the curves of Fig. 3 with those of Fig. 8—the increase in oxygen liberation with rise of temperature is much more marked in the former case than in the latter—and, secondly, by comparing the amount of dissociation taking place at oxygen pressures below 5 cm. of mercury as shown by (*a*) the isotherm at 1,272° C. in Fig. 6, and (*b*) the pressure/composition curve at 1,272° C. for monocalcium ferrite in Fig. 10. It is thus evident that the lime has a marked stabilising effect on the Fe_2O_3. How far this effect would be felt in monocalcium ferrite melts at temperatures considerably higher than 1,272° C. is not shown by the data, though it may be expected to decrease considerably, resulting in a greater degree of dissociation. Fig. 11, however, for $2CaO.Fe_2O_3$, shows what occurs at 1,485° in the presence of a considerably larger proportion of lime. With initially pure Fe_2O_3 at this temperature the dissociation at oxygen pressures even of the order of half an atmosphere will be between 80 and 90 per cent., while Fig. 11 shows only 4 per cent. at 30 cm. pressure of mercury and round about 6 per cent. at 10 cm. pressure. For this reason it is, in all probability, dicalcium ferrite rather than the monocalcium compound which plays so important a part in the basic open-hearth process. The work now in progress may shed further light on this point.

The authors desire to thank the Metallurgy Board of the Department of Scientific and Industrial Research for permission to publish this work, and also to acknowledge the receipt of financial aid from the Board which made the research possible.

APPENDIX.—*Method of Calculating the Composition of the Solid Phase for the Isotherms of Fig.* 6.

From the individual pressure/temperature curves, examples of which are shown in Fig. 3, the composition of the solid phase can be obtained in the following manner:

At a temperature of 1,272° C. (14·00 m.-volt on the thermocouple) curve XVII., Fig. 3, shows a pressure in the tube of 4·00 cm. of mercury. By producing the linear portion of the curve it is seen that, if there had been no evolution of oxygen from the Fe_2O_3, the pressure would have been 2·90 cm. of mercury at this temperature. There is therefore an increase due to oxygen liberation of 1·10 cm. of mercury.

As determined empirically, the pressure in the tube increases 2·23 times between room temperature and 1,272° C. (the "expansion factor" mentioned in the text). Hence the "equivalent"

difference of pressure at room temperature (22° C.) is 0·493 cm. of mercury. The volume of the apparatus was 1,800 c.c.; the weight of oxygen liberated, 0·0145 grm.; and the original weight of Fe_2O_3, 3·0020 grm. Hence the molecular percentage of Fe_3O_4 was 10·88 per cent. at an oxygen pressure of 4·00 cm. of mercury.

By this method a series of compositions corresponding to various pressures was calculated for the temperatures 1,200° C. (13·00 m.-volt), 1,272° C. (14·00 m.-volt), 1,345°C. (15·00 m.-volt), and 1,415° C. (16·00 m.-volts).

TABLE I.—*Isotherm at* 1,345° *C.* (15·00 *m.-volt*).

"Expansion Factor," 2·30.

Curve No.	Equilibrium Press. Cm. Hg.	Pressure Due to Initial Oxygen in Tube. Cm.	Difference. Cm.	Equiv. Diff. at Room Temp. Cm.	Volume of Apparatus. C.c.	Weight of Oxygen Liberated. Grm.	Original Weight of Fe_2O_3. Grm.	Molecular Percentage of Fe_3O_4.
IX.	19·20	16·05	3·15	1·37	1800	0·0428	9·7243	9·22
X.	15·30	11·90	3·40	1·48	1800	0·0462	9·7243	10·0
XI.	24·60	22·60	2·00	0·87	1800	0·0272	9·7243	5·75
XII.	35·90	34·30	1·60	0·69	1800	0·0218	9·7243	4·59
XIII.	11·70	1·61	10·09	4·38	1800	0·1370	9·7243	32·9
XIV.*	11·75	..	..	..	1800	0·1683	9·7243	42·0
XV.*	11·70	..	..	..	1800	0·2668	9·7243	75·5
XVI.	11·80	8·85	2·95	1·28	1800	0·0401	3·0020	30·9
XVII.	9·10	3·05	6·05	2·63	1800	0·0824	3·0020	75·4
XVIII.	7·50	1·80	5·70	2·48	1800	0·0775	3·0020	69·5
XXII.	39·40	37·90	1·50	0·65	1850	0·0210	12·9020	3·31
XXIII.	67·40	66·60	0·80	0·35	1850	0·0112	12·9020	1·77
XXVI.	41·90	39·60	2·30	1·00	1850	0·0322	21·1195	3·11
XXVII.	55·70	54·20	1·50	0·65	1850	0·0210	21·1195	2·01
XXVIII.	75·30	74·00	1·30	0·56	1850	0·0182	21·1195	1·74

*The calculations from curves XIV. and XV. were obtained indirectly, as explained in the text.

The actual weights of Fe_2O_3 taken were varied. For example, in Fig. 3, curves XVI., XVII. and XVIII. were obtained when using 3·0020 grm. of Fe_2O_3, and curves XIII., XIV. and XV. with 9·7243 grm. Curves XIV. and XV. were taken after curve XIII. had been completed, by drawing off known amounts of oxygen, so that, even with all the oxygen in the tube combined with the oxide, there would still have been some Fe_3O_4 present. In the calculations based on these curves this had to be taken into account. The values obtained for the isotherm at 1,345° C. are given in Table I.

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CORRESPONDENCE.

Dr. A. McCance (Glasgow) wrote that he considered this paper to be an important contribution to the scientific study of slags. There was no question that the examination of the dissociation oxygen pressure of slags was the fundamentally correct method for measuring their oxidising power at any temperature. Hitherto, the difficulties of applying this method had prevented its application, and few experimenters had cared to tackle these difficulties.

The consistent results of the authors clearly indicated, however, that their methods had proved successful in overcoming all the interfering factors and that their results possessed a high degree of accuracy. Incidentally, they had thrown new light on the complicated interactions between the oxides of iron in the solid state, and the thermal diagram which they gave in Fig. 7 was of importance in this respect.

In considering the dissociation pressures which they had found for the calcium ferrites, the facts that these pressures varied with the composition, and decreased when the composition was varied on either side of that for the exact compound, seemed to indicate that the compounds largely existed at the high temperatures in a state of dissociation, since it would follow from the ordinary law of mass action that an increase in either the lime or the ferric oxide would result in a larger percentage of the ferrite being formed and consequently a diminution of the free ferric oxide and a lowering of the dissociation pressure.

Further confirmation of this seemed to be obtained from the fact which the authors had found, that the addition of ferrous oxide to the ferrites had also resulted in a marked lowering of the dissociation pressure. It raised a doubt, therefore, as to the existence of either of these compounds at the temperature of the melting furnace, and it would be of interest to know the opinion of the authors regarding this.

The occurrence of crystalline ferrites in cold slag could readily be accounted for, of course, by their formation during the cooling-down process. Before this could be definitely affirmed, however, it would be necessary to work with mixtures approximating more closely to the compositions of basic slags, and it was useful to know that the authors intended to continue this investigation along this line.

In the diagrams shown in Figs. 10 and 11, had it been possible to correlate the lowering of the dissociation pressure for a given percentage of FeO with the assumption that this FeO was com-

bined wholly with the Fe_2O_3 ? If that could be done and if the assumption could be made that the FeO was wholly combined to form magnetite it would simplify in one aspect the problem of slag constitution at high temperatures.

AUTHORS' REPLY.

Professor HAY, in reply, wrote that he wished to thank Dr. McCance on behalf of his colleagues and himself for his instructive comments. He was pleased to see that Dr. McCance was in complete agreement with their method of attacking the problem.

The evidence of the thermal curves suggested that the compounds were, at least in part, dissociated on melting. The pressure curves showed that the initial pressure developed by the compounds on melting agreed with that of Fe_2O_3, but immediately ferrous iron was present there was a marked drop in the equilibrium pressure, as seen on comparing Figs. 9 and 10. It would therefore appear that the pressure resulted from the dissociation product and not from the compound as such. From a consideration of all the evidence available, the authors were of the opinion that at the temperatures of the open-hearth furnace the calcium ferrite compounds were not completely dissociated.

It had not been possible to determine the state of the ferrous iron in the liquid phase of the ferrites, and for this reason the results had been expressed as FeO plus Fe_2O_3, no assumption being made as to the state of combination of the ferrous and ferric iron. Calculation to Fe_3O_4 gave a curve of the same type.

THE DEFLECTION OF THE ROLLS IN PLATE, SHEET AND STRIP MILLS.*

By J. SELWYN CASWELL, M.Sc., A.M.I.Mech.E., Assoc.M.Inst.C.E.
(University College, Swansea.)

Synopsis.

One of the chief requirements in the rolling of some strip and sheet products is accuracy and uniformity of gauge. The methods of approach to accuracy are described, and detailed consideration is given to an important related matter, namely, the deflection of the rolls. The relationship between the rolling loads and the roll deflections is discussed, and the importance of it, when a high degree of accuracy is required, is emphasised.

In the calculation of the approximate roll deflections, consideration is given to the combined effect of the longitudinal flexural stresses and the shear stresses. The limitations of the ordinary bending theory are discussed, and reference is made to the recent photo-elastic researches on the bending of beams having roll proportions, that is, a small value of the span/depth ratio.

Formulæ are derived for use in calculating the approximate values of the roll deflections at the centre of a roll and at points removed from the middle of the roll. The formulæ are applied in a particular case to illustrate their use and to indicate the order of magnitude of the roll deflections. The results are compared with some interesting mill observations relating to roll deflection, and the need for further experimental observations is urged.

Close approach to correct and uniform gauge is one of the chief requirements in a wide range of plate, sheet and strip products. The greatest degree of accuracy is required in the case of strip rolling, and a gauge tolerance of $\pm$ 0·0001 in. may be imposed.

* Received August 22, 1934.

The art of the roll manufacturer and the rolling-mill engineer is directed towards the provision of rolls which have a surface profile suitable for accurate rolling under normal working conditions. The working surface is given a camber or concavity which compensates for the slight changes which are produced under working conditions. These conditions arise mainly as a result of temperature variations along the rolls and the deflection of the rolls under the rolling loads.

In hot-rolling there is a fall of temperature from the middle towards the ends of the rolls, and, consequently, the working surface of the roll is made slightly concave. In cold-rolling a reverse temperature condition may exist, that is, a fall of temperature from the bearings towards the middle of the rolls. For this condition it is necessary to make the working surface of the roll slightly convex. When there is no temperature variation along the rolls, a slight camber is necessary to compensate for the deflection of the rolls.

Reference may be made here to an interesting point which is sometimes overlooked, namely, the connection between the rolling load and the roll surface profile. The initial camber or concavity turned or ground on a roll corresponds to some best condition of temperature difference in the roll and value of the rolling load. When the normal working temperature conditions are reached in a mill and when there is a rythmic flow of stock between the rolls, the temperature differences remain fairly steady. The roll deflection, however, varies with the changing values of the rolling load, and unless care is taken undesirable variation of gauge across a sheet or strip may be produced by a rolling load which is either too large or too small. In the early stages of cold-rolling processes, there is a rapid increase in the resistance to deformation as a result of the work-hardening of the material. Under such conditions it may be necessary carefully to adjust the draughts in order that the rolling load may be kept fairly constant. This control of the draught would be rendered easier, no doubt, if a roll pressure recording apparatus was used. Suitable apparatus for this purpose for permanent use has been described elsewhere.[1]

In some rolling processes the roll face wears rapidly, and to compensate for this it may be necessary to produce some appropriate change in the temperature conditions along the rolls by applying some heating or cooling agent to parts of the roll face.

Calculation of the Roll Deflection.—The diameter of the rolls is usually large in relation to the length, and, consequently, a large part of the deflection is due to shear stress. In the notes below formulæ have been deduced for calculating the approximate deflection due to the longitudinal stresses and the shear stresses. The accuracy of the numerical results obtained is open to some

doubt, however, because of the uncertainty relating to the rolling loads, the elastic constants for the roll material and the unsuitability of the ordinary beam theory when the span/depth ratio is small. Photo-elastic researches[2] on the bending of short deep beams show that the stress conditions are more complex than those associated with the bending of beams with a high span/depth ratio. The distribution of the shear stress across a section does not follow the usual parabolic distribution, and the

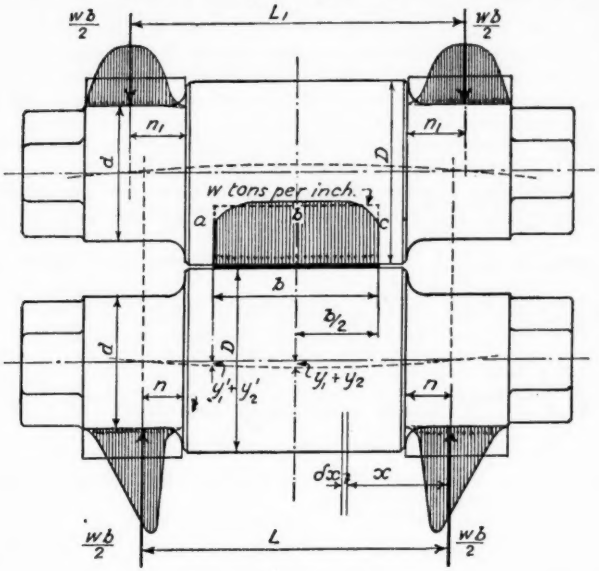

FIG. 1.—Pressure Variation along the Rolls.

investigations suggest that, in the case of the rolls under discussion, it would be nearer the true condition to assume a uniform distribution of shear stress across a section. This assumption has been made in obtaining the formula for the deflection due to shear, and the formula obtained is compared with one for which the shear stress is assumed to follow a parabolic distribution. The deflection formulæ have been used for calculating the probable deflection in a particular case, and the results are compared with an interesting mill observation relating to roll deflection.

The character of the pressure variation over the contact area between the roll and the stock in a longitudinal and a circum-

ferential direction has been investigated in great detail by Lueg.[3] The results suggest that the general character of the variation along the rolls is as shown by the line *abc* in Fig. 1. In a large number of mills, the rolls are mounted in plain bearings, and the approximate variation of the pressure along the bearings is shown in the same diagram.

It will be noticed that the pressure variation along the bottom roll bearings differs from that along the top roll bearings. The reason for this is that the top roll bearings and riders are pivoted against the ends of the mill screw pins, whereas the bottom roll bearings are usually set solid on the base of the housing window. It is probable, therefore, that there is an almost symmetrical variation of the pressure along the top roll bearings, and an almost gradual fall of pressure outwards along the bottom roll bearings. Consequently, the effective span for the bottom roll would be slightly less than that for the top roll.

The Approximate Deflection, y_1, *due to the Longitudinal Stresses.*—This may be obtained by taking the sum of the integrations of $\frac{1}{E}\int\frac{M x dx}{I}$ between the appropriate limits (see Fig. 1), over three stages to the centre of the roll, that is :

$$y_1=\frac{1}{EI_2}\int_0^n \frac{wb}{2}x^2dx+\frac{1}{EI_1}\int_n^{\frac{L-b}{2}}\frac{wb}{2}\,x^2dx+\frac{1}{EI_1}\int_{\frac{L-b}{2}}^{\frac{L}{2}}\left[\frac{wb}{2}x-\left\{x-\left(\frac{L-b}{2}\right)\right\}\frac{w}{2}\right]x\,dx$$

where M = bending moment at any section distant x from the line of the resultant pressure on a bearing,
I = moment of inertia of the section.

After integrating and substituting the limits for each stage, this reduces to :

$$y_1=\frac{wb}{384EI_1}\left\{8L^3-4Lb^2+b^3+64n^3\left(\frac{I_1}{I_2}-1\right)\right\} \quad . \quad . \quad . \quad . \quad . \quad \text{(i)}$$

where I_1 and I_2 are the moments of inertia of the body cross-section and bearing cross-section, respectively.

If $\pi D^4/64$ and $\pi d^4/64$ are substituted for I_1 and I_2, respectively, the final form of the expression is :

$$y_1=\frac{wb}{18{\cdot}8\,ED^4}\left[8L^3-4Lb^2+b^3+64n^3\left\{\left(\frac{D}{d}\right)^4-1\right\}\right] . \quad . \quad . \quad . \quad \text{(ii)}$$

in which y_1 = the approximate deflection due to the longitudinal stresses, in inches.
w = the load per inch along the roll, in tons.
b = the width of the sheet or strip passing between the rolls, in inches.

E = the modulus of elasticity of the roll material, in tons per square inch.
D = the diameter of the roll body, in inches.
d = the diameter of the roll bearings, in inches.
L = the length between the lines of the resultant pressures on the bearings, in inches.
n = the distance between the edge of the roll body and the line of the resultant pressure on the adjacent bearing, in inches.

The Approximate Deflection, y_2, *due to the Shear Stresses.*— If it is assumed that the shear stress is uniform over any section of the roll, the total deflection due to shear is given approximately by the sum of the integrations of $\frac{1}{C}\int\frac{Fdx}{A}$ between the appropriate limits over the three stages to the centre of the roll, that is :

$$y_2 = \frac{1}{CA_2}\int_0^n \frac{wb}{2}\,dx + \frac{1}{CA_1}\int_n^{\frac{L-b}{2}} \frac{wb}{2}\,dx + \frac{1}{CA_1}\int_{\frac{L-b}{2}}^{\frac{L}{2}} \left[\frac{wb}{2} - w\left\{x - \left(\frac{L-b}{2}\right)\right\}\right] dx$$

where F = the total shear force at any section, in tons.
A = the cross-sectional area at any section, in square inches.
A_1 and A_2 = the cross-sectional area of the body and the bearings, respectively, in square inches.
C = the modulus of rigidity of the roll material, in tons per square inch.
and the other terms as already indicated.

After integrating and substituting the limits, the above expression reduces to the final form :

$$y_2 = \frac{wb}{\pi CD^2}\left\{L - 2n\left(1 - \frac{D^2}{d^2}\right) - \frac{b}{2}\right\}^* \quad . \quad . \quad . \quad . \quad . \quad \text{(iii)}$$

Then the total deflection at the centre of the roll is equal to $y_1 + y_2$ in.

The Approximate Deflection at the Edge of the Stock, y^1_1 *and* y^1_2.— The approximate deflection of the roll at the edge of the stock is given by the sum of the values y^1_1, and y^1_2, calculated from the following formulæ :

$$y^1_1 = \frac{wb}{2{\cdot}36ED^4}\left[(L-b)^3 + 8n^3\left\{\left(\frac{D}{d}\right)^4 - 1\right\}\right], \quad . \quad . \quad \text{(iv)}$$

due to the longitudinal stresses, and

$$y^1_2 = \frac{wb}{1{\cdot}57C}\left\{\frac{n}{d^2} + \frac{1}{2D^2}(L-b-2n)\right\}, \quad . \quad . \quad \text{(v)}$$

due to the shear stresses.

*See Appendix.

By making $b = L$, $I_2 = I_1$, and $n = 0$, formula (i) reduces to

$$\frac{5wL^4}{384EI_1}$$

which is the simple expression for the deflection at the centre of a uniform section beam carrying a uniformly distributed load over the whole of the span.

The same substitution in formula (iii) reduces the expression to

$$\frac{wL^2}{2\pi CD^2}.$$

If A_1 is substituted for $\pi D^2/4$ the formula becomes

$$\frac{wL^2}{8CA_1}$$

which is the common expression for the deflection due to shear stresses, assumed to be uniformly distributed over any cross-section, for a uniform section beam carrying a uniformly distributed load over the whole of the span. If a parabolic variation of the shear stress is assumed, the formula is then

$$\frac{wL^2}{7{\cdot}2\ CA_1}$$

and this would give slightly greater values of the shear deflection. For short beams, it is probable that values given by the preceding formula would be nearer to the actual values of the deflection under the conditions just defined. Comparison of the simple formulæ just given shows the difference between the results produced by the different assumptions regarding the distribution of the shear stress. The lower deflection values given by formulæ based on a uniform distribution of the shear stress are to be preferred when the span/depth ratio is small.

Practical Application of the Formulæ.—As an illustration of the results obtained with the formulæ, the separate and total deflections at the middle of a cast-iron roll and at a point corresponding to the edge of the rolled stock have been calculated. The calculations relate to a roll which was used in a mill in which the experimental observations referred to earlier were made. The values of the terms in the formulæ are as follows :

w = 22 tons per in.
b = 21 in.
E = 8,500 tons per sq. in.
D = 23 in.
L = 38 in.
n = 5 in.
d = 16½ in.
C = 3,500 tons per sq. in.

Deflection at the centre of the roll :

Due to the longitudinal stresses . . .	0·0042 in.
Due to the shear stresses	0·0029 „
Total deflection at the centre	0·0071 „
Combined effect due to the deflection of two rolls.	0·0142 „

Deflection of the roll at the edge of the stock :

Due to the longitudinal stresses . . .	0·00063 in.
Due to the shear stresses	0·0021 „
Total deflection of roll at the edge of the rolled stock	0·0027 „
Combined effect at this point due to the deflection of the two rolls	0·0054 „

At the centre of the roll, the deflection due to shear is equal to 69 per cent. of the deflection due to the longitudinal stresses.

At the edge of the stock, the deflection produced by shear is 230 per cent. greater than that produced by the longitudinal stresses.

The difference produced between the middle of the roll and the edge of the stock, as a result of the combined effect of the deflection of the two rolls, is $(0{\cdot}0071 - 0{\cdot}0027) \times 2 = 0{\cdot}0088$ in.

The effect of this difference on the thickness of the stock rolled would depend on the " no-load " camber or " sweep " of the roll. Its value would change according to the change in the value of the rolling load, and it is this alteration of the roll deflection which should be avoided when a high degree of accuracy of gauge is required across the width of the rolled stock.

Experimental Observations Relating to Roll Deflection.—The direct determination of the deflection of mill rolls under load is not easy. Some interesting deductions may be made in this connection, however, when a heated piece of flat stock is stalled in the mill, that is, a stoppage of the mill while the piece is between the rolls, as a result of either excessive draught or inadequate driving torque. The point of interest associated with a stall is the change of thickness of the stock just before and after the stall occurs. When the resistance to deformation of the heated stock arrests the motion of the rolls, there is, at first, a gradual reduction of the rolling speed, and, consequently, a reduction in the rate of deformation. There is a gradual and partial dissipation of the strain energy normally stored during a pass. When the mill is brought to rest, the dissipation of strain energy continues until a condition of pressure equilibrium is reached between the rolls and the piece which is held stationary between the rolls. As the strain energy is being given up, there are corresponding elastic changes in the mill components. These changes produce a slight shortening of the stretched standards, a slight approach

to normal dimensions of the components under compression and a slight reduction of the roll deflections.

With a view to obtaining a rough check on the calculated values given above, the author sent a request to several works for the supply of a stalled piece. After a few weeks an accidental stall occurred and the stalled piece was sent to him.

The details of the stall are shown in Fig. 2. It will be noticed that the stalling produced slight thinning of the piece at the " bite " and, consequently, an increase of the contact area. Under normal rolling conditions, the horizontal length of the bite

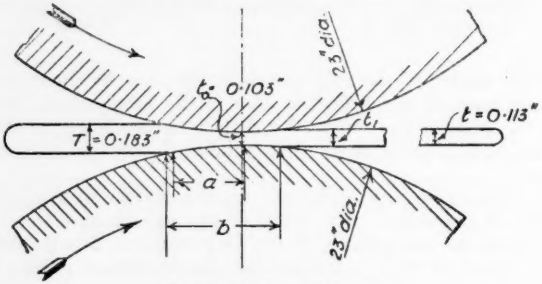

FIG. 2.—Stalled "Piece."

would be the length marked *a* in the diagram. After the stall and the partial dissipation of the strain energy in the mill, the horizontal length of the bite was increased to the length marked *b*.

Careful measurements of the thickness of the piece were made at the points shown along the middle and the sides of the piece. These measurements were plotted to a large scale as shown in Fig. 3. The diagram indicates the gradual thinning which occurred as the speed of the mill was reduced, and also the local thinning while the piece remained stationary between the rolls. The dotted line denotes the probable change of thickness that would exist under normal conditions.

The total thinning was 0·010 in.; this was produced by the combined effect of the elastic changes in the mill, and these occurred mainly in the mill housings and the rolls.

It was necessary to calculate the probable amount of the elastic recovery of the mill housings before the amount attributable to the reduction of the roll deflection could be obtained. Experimental observations on the stretch of the housings of a mill of the type considered have been made by the author. A Tudsbery stress recorder was attached to one of the pillars of the mill housings, and the value of the elastic stretch recorded under rolling conditions similar to those associated with the stalled

piece was 0·004 in. Consideration of the final pressure condition between the rolls and the stalled piece suggests that the elastic recovery of the housing pillars would be approximately 0·002 in., thus leaving a residual elastic stretch of 0·002 in. The elastic change produced by the reduction of the deflection of the two rolls would then be approximately 0·010 in. – 0·002 in. = 0·008 in., thus giving 0·004 in. for each of the rolls.

The calculated total deflection of one roll, given earlier, is 0·007 in., and the difference between this and the value 0·004 in. given above is 0·003 in. This amount approximately represents the unrecovered amount of the roll deflection.

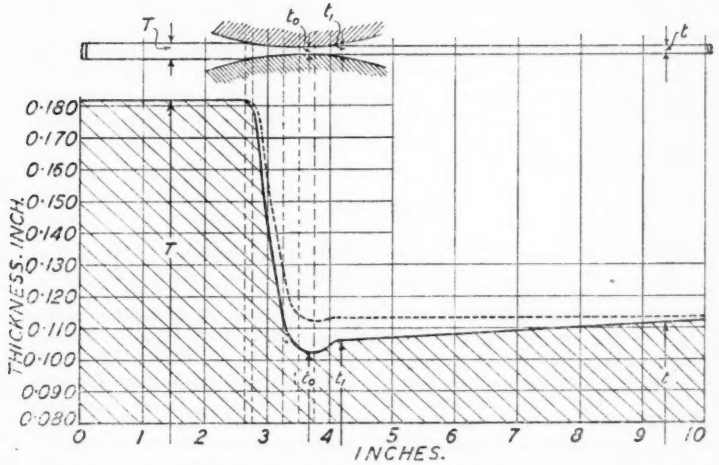

FIG. 3.—Variation of Thickness of Stalled "Piece" in the Direction of Rolling.

If the ratio of the shear deflection to the deflection due to the longitudinal stresses is assumed to remain 0·69, then the proportion of 0·003 in., which would be the result of the longitudinal stress, is 0·003/1·69 = 0·0018 in. With this value, the approximate value of the residual load per inch, w_1, along the bite can be determined. Since all the terms, other than the load per inch run along the bite, in formula (ii) remain unchanged, the load per inch is proportional to the deflection produced by the longitudinal stresses. Consequently $0{\cdot}0018 : 0{\cdot}007 :: w_1 : w$, and therefore $w_1 = (0{\cdot}0018/0{\cdot}007) \times w$; w is equal to 22 tons, thus giving a residual load, w_1, equal to 5·6 tons per in., or a total of 118 tons for the whole width of the stalled piece.

Those who have had experience in the removal of stalled pieces from a mill will know that this residual load gives rise to considerable difficulty in releasing the screw pins.

Perhaps sufficient has now been indicated to demonstrate the relationship between roll deflection and accuracy in the rolling of flat stock and also to show the method of obtaining an approximate estimate of the amount of the roll deflection. In view of the uncertainty relating to the magnitude and the distribution of the stresses in the rolls, there is need for careful experimental investigation on this matter. This short paper is presented merely as an effort towards a fuller understanding of one of the numerous characteristics associated with the art of rolling metals.

In conclusion, the author desires to thank Professor F. Bacon, M.A., Head of the Engineering Department, University College, Swansea, for his kindness in providing facilities for the work, and also the Fairwood Tinplate Co., Ltd., Gowerton, for their kindness in supplying the stalled piece and the particulars of the rolling conditions related thereto.

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(2) E. G. COKER and L. N. G. FILON: "A Treatise on Photo-Elasticity." Cambridge, 1931: University Press.

(3) W. LUEG: "Distribution of Pressure and Flow of Material in the Gap between the Rolls of a Rolling-Mill." *Stahl und Eisen*, 1933, vol. 53, p. 346.

APPENDIX.

The formulæ Nos. (iii) and (v) may be written in the more convenient form shown below:

$$y_2 = \frac{wb}{\pi CD^2}\left[L - \frac{b}{2} + 2n\left\{\left(\frac{D}{d}\right)^2 - 1\right\}\right] \quad . \quad . \quad . \quad . \quad . \quad \text{(iii}a\text{)}$$

$$y^1_2 = \frac{wb}{\pi CD^2}\left[L - b + 2n\left\{\left(\frac{D}{d}\right)^2 - 1\right\}\right] \quad . \quad . \quad . \quad . \quad . \quad \text{(v}a\text{)}$$

CORRESPONDENCE.

Professor E. G. Coker, F.R.S. (London) wrote that the initial camber required for a pair of rolls in a mill for producing flat plates and sheets was an extremely difficult matter from a mathematical standpoint, for, as the author rightly pointed out, the simple formulæ of engineering text-books did not apply to very short beams of great depth. The solution he offered had the great merit of recognising this salient fact and in his calculations for the deflections produced by shear he took the shear stress distribution to be uniform throughout the depth of the roll as a first approximation to the actual distribution, which latter was somewhat more complicated, as was first shown by Filon and subsequently verified by photo-elastic experiment.

This approximation was probably quite a good one along the distance occupied by the plate or sheet, but in the free gaps between the rolls on each side the experiments of Fukuhara[1] on short beams indicated different types of shear stress distribution, varying from point to point along the length of the roll.

As a summary of shear stress theory and experiment for beams of this type had already appeared it was only necessary to give a reference[1] to the evidence on which the author's choice of approximation was based.

This was the most accurate part of the calculations, since the complexity of the bending moment problem compelled the author to fall back on the simple theory of beams not truly applicable to this case. Even so his analysis brought out some interesting facts, and more especially the large amount of deflection produced by the shear loading.

Mr. C. E. Davies (Bedford) wrote that Mr. Caswell had made a very careful and interesting study of this most important factor in all strip and sheet rolling, especially important in view of the increasingly severe requirements in regard to the accuracy of rolled products.

In the case of hot-rolling sheets approximately to finished gauge in two-high mills, where the rolls were relatively long in proportion to their diameters, the deflection of the rolls—which was unavoidably variable—was a serious matter, causing variation in gauge, both across any one sheet and from sheet to sheet. Temperature difference from end to centre of rolls was another variable factor, and it would seem almost impossible to grind rolls to such a camber as would counteract these causes of inaccuracy under all conditions in practice with sufficient exacti-

[1] *See* Coker and Filon, "A Treatise on Photo-Elasticity." Cambridge University Press.

tude to ensure that the product would be within the fine tolerances required.

The modern four-high mill with large and stiff supporting rolls would certainly reduce the deflection under load and would, to a large extent, eliminate this cause of variation in gauge; but with a hot mill, the temperature factor was still a problem.

The present tendency to supersede hot-rolling in the finishing stages by cold-rolling would appear to be the only sure method of securing a more accurate product. Here the four-high cold sheet or strip mill would certainly fulfil requirements, as besides limiting deflection to a minimum and consequently requiring extremely small convex camber for the working rolls, the provision of modern anti-friction bearings for the support rolls eliminated temperature differences due to bearing heat, which would otherwise introduce a cause of variable gauge.

There was, of course, still the heating of the roll barrel due to the work of deformation effected by the rolls, which tended to cause a variation in roll diameter and generally resulted in a convex camber effect, but there again, the modern practice in roll cooling would ensure a reasonably uniform roll temperature during rolling. The camber effect due to small temperature differences from the centre to the ends of the roll barrel was generally advantageous, and, with rolls ground parallel, would compensate for any unavoidable deflection or deformation of the rolls under load.

Generally, the writer was of the opinion that, in future, very little sheet rolling would be accomplished by two-high rolls, and, except for light planishing work, the four-high mill, already increasingly installed, would be the only type used.

Mr. A. ALLISON (Sheffield) wrote that Mr. Caswell's paper was a further valuable study of the problem of rolling thin steel strips and sheets with regularity of gauge, and there was no doubt that mathematical analysis would provide great assistance when the necessary physical data were ascertained.

The difference in gauge of 0·009 in. between the centre and edges of the sheet found by Mr. Caswell was a measurement of one of the factors to be considered. That variation was overcome by altering the sweep of the roll and also by regulating the expansion due to heating. Other factors were the ratio of the roll diameter to the length and the rolling load applied.

Mr. Caswell did not appear to have recorded the variation in gauge on the stalled piece from edge to edge, which would have had a bearing on his calculations. It would also appear that the thinning at the point of contact was due to loss of motion and also local heating.

It was clear that rolling practice varied not only from one locality to another, but also between different mills, and as the

individual factors were studied and measured it would be possible to arrive at optimum conditions, comprising the desirable balance between the elastic changes in the mill components, the deflection and fatigue of the rolls, and the heating conditions and drafts employed.

AUTHOR'S REPLY.

Mr. CASWELL, in reply, thanked the contributors for their observations on the paper. He was particularly glad to have Professor Coker's views, and these confirmed the author's contention that the method of solution submitted would give only approximate results.

It was interesting to note, however, that the indirect method of checking the results suggested that the calculated values might not be greatly in error. A further indication could be obtained from a consideration of the thermal condition of the rolls in conjunction with the dimensions of the hollowness ground in the rolls when they were cold (temperature, approximately 15° C.). The hollowness here referred to the difference between the radii at the middle of the roll and at the end of the roll body. For a roll 23 in. in diam., the hollowness over a body length of 29 in. was 0·012 in. Under working conditions the surface temperature of the roll at the centre was approximately 450° C., and at the ends approximately 350° C.

The temperature through the roll was not uniform, and if it was assumed that the average temperature along a diameter at the middle of the roll was 380° C. and that along a diameter at the cooled end of the roll it was 250° C., the following figures were obtained for unrestricted thermal expansion. It was assumed that the coefficient of linear expansion for cast iron was $1 \cdot 112 \times 10^{-5}$ in. per in. per ° C. :

Increase of radius at the middle of roll	0·0463 in.
Increase of radius at the end of the roll	0·0298 „
Difference	0·0165 „
Deduct the initial amount of hollowness	0·0120 „
Amount of fullness or camber on the unloaded roll under working conditions	0·0045 „

The estimated deflection produced by the rolling load for one roll was 0·0044 in. for the whole length of the roll, and the calculated fullness on a length of 29 in. was 0·0045. The fullness was then approximately cancelled out by the roll deflection. Under such conditions, the stock would be rolled with fairly

uniform thickness, except for the unavoidable thinning at the edges due to lateral spread of the stock and slight variations due to roll face compression. It was necessary to note, however, that the amount of thermal expansion was affected slightly by the strain accompanying the thermal stresses which were set up in the roll.

Mr. Davies and Mr. Allison had drawn attention to the numerous factors affecting the thickness of sheets, and the author agreed with Mr. Davies' views regarding the advantages of cold-rolling and the use of four-high mills for the attainment of greater accuracy. The edge-to-edge variation of gauge referred to by Mr. Allison had been measured by the author, and a difference of 0·002 in. was obtained as the variation produced by the partial reduction of the deflection of the rolls.

AN INVESTIGATION OF SPRING STEELS.[1]

By Professor J. H. ANDREW, D.Sc., and G. T. RICHARDSON, M.Met.
(Department of Metallurgy, The University of Sheffield).

Summary.

The following is an account of an investigation of the manufacture of spring steels, from the billet stage to that of the heat-treated plate. The first part deals with silico-manganese steels and the second with chromium-vanadium and plain carbon steels in addition.

Details of heating for rolling, of rolling, and of the final heat treatment are given.

The important feature emphasised throughout this paper is the decarburised layer resulting from furnace treatment at different periods of the process. It has been shown by previous workers that a decarburised surface results in a considerable diminution in the fatigue strength.

Hardness measurements and micro-observations have shown that a silico-manganese steel is the most susceptible of the three to decarburisation. This decarburised layer is reduced to a minimum by a high temperature of soaking prior to rolling, and the qualities of the springs are improved by a high degree of reduction per pass during rolling.

It has been shown that in the final hardening and tempering process a thick tenaceous scale results in an insufficient hardening of the steels, whereas a clean decarburised surface gives rise to a greater hardness in the centre of the spring plates.

Silico-manganese steels require a high temperature for hardening to produce homogeneity throughout the plate, whereas chromium-vanadium steels are much less susceptible to temperature, and are easily treated to give a uniform hardness value throughout.

From the purely metallurgical standpoint it appears that the chromium-vanadium steel is the easiest to treat, and, generally speaking, gives the most satisfactory results.

It has been shown by Hankins and Ford[2] and by Hankins and Becker[3] that the fatigue strength of spring steels is seriously reduced by faulty surface conditions such as arise through the surfaces being decarburised during the manufacturing process.

The seriousness of surface decarburisation was fully realised by the Sheffield spring makers, and a Committee was formed to deal with the matter. It was at the instigation of this Committee that the following investigation was carried out, and the authors would like to record their indebtedness for their guidance in formulating methods of attacking this problem.

[1] Received February 15, 1935.

[2] *Journal of the Iron and Steel Institute*, 1929, No. I. p. 217.

[3] *Journal of the Iron and Steel Institute*, 1931, No. II. p. 387.

TABLE I.

Furnace.	Time in Furnace.	Temp. at Removal. ° C.	Temp. at Commencement of Rolling. ° C.	Temp. at Finish of Rolling. ° C.	Time from Furnace to First Pass. Sec.	Time of Rolling.	No. of Passes.	Depth of Decarburisation, in thousandths of an inch.									
								Billets.				Rolled Plates.				Heat-Treated Plates		
								Visible Depth.		Extreme Depth from Hardness Curves.		Visible Depth.		Extreme Depth from Hardness Curves.		Visible Depth.		Extreme Depth from Hardness Curves.
								B.*	W.*	B.*	W.*	B.*	W.*	B.*	W.*	B.*	W.*	
Original Billets	2 hr.	1150 to 1200 approx.	..	950 to 1000 approx.	..	..	..	Difficult to measure.		40		..	..	..	..	..	..	
X.	1 hr. 40 min.	1028	..	853	18	1 min. 50 sec.	8	30	40	50	60	8	10	16	23	8	8	11
Y.	1 hr. 42 min.	1290	1267	1065	17	1 min. 5 sec.	7	Not visible.	30	35	50	Not visible.	12	11	17	2	5	9
Z.	5 hr. 7 min.	1260	1250	1023	15	1 min. 5 sec.	9	30	40	60	70	14	18	23	25	8	8	17
Heat treatment: Heated for 17 min. at 950° C. and oil-quenched. Tempered for 10 min. in lead at 450° C.												2-ft. length of plate rolled from furnace *Y* heat-treated after grinding 0·015 in. (as a minimum) from each side.				Not visible.		6

Description of Furnaces: *X.*—Coal-fired, billets in contact with burning coal.
Y.—Automatically fed, coal-fired, semi-continuous furnace, always with a smoky atmosphere.
Z.—Semi-continuous coal-fired furnace with straight-line temperature gradient from 700° to 1,300° as recorded during this experiment.

* B.=best; W.=worst.

At the outset, one type of steel was selected for research, namely, a silico-manganese steel containing 0·45 per cent. of carbon, 2·02 per cent. of silicon and 0·78 per cent. of manganese.

Six billets taken from the same ingot were selected for rolling and treatment in three different works, which at the time were using different types of furnaces in connection with their rolling-mills. Table I. gives the particulars recorded, from which it will be observed that billet *X* was rolled at a comparatively low temperature, billet *Y* at a high temperature, whilst not only was billet *Z* rolled hot, but it had remained for a prolonged time in the reheating furnace. With regard to *Z*, it must be explained that this prolonged time of reheating was not the customary practice, and occurred owing to a breakdown in the mill. Further, the temperature in this furnace remained moderately low for the greater part of the time, the temperature only being raised some little time prior to taking out the billet for rolling.

The depth of decarburisation was measured by the Vickers hardness machine, and by means of micro-examination (visible depth). The figures given show clearly that the microstructure is not a correct criterion of the amount of decarburisation, the figure given by hardness determinations being considerably greater.

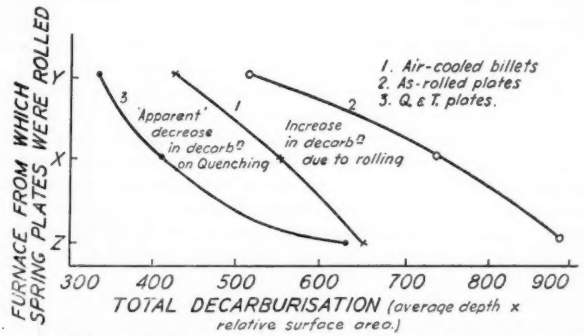

FIG. 1.—Influence of Rolling and Quenching on Decarburisation during rolling of Si-Mn steel billets into spring plates and their subsequent quenching.

Perhaps the most interesting feature of these results is with respect to the small amount of decarburisation in billet *Y*. This was attributed to the protective type of scale that formed. This scale gave the impression of having fused, therefore virtually sealing the metal from the attack of decarburising gases. Fig. 19 (Plate I.), which is a photograph of sections of the billets, shows clearly this effect.

Sections were taken from each of the three billets after reheating for rolling, after rolling into plates, and after quenching and tempering.

The reason for the decrease in the depth of decarburisation after rolling as compared with the original billet is, of course, the increase in surface resulting from the rolling. This amounted to 3·7 times the billet surface. In Fig. 1 the depth of decarburisation of the three samples *X*, *Y*, and *Z* has been plotted in order to show the increase in decarburisation that actually results from the rolling operation, apart from the reheating. In this figure the values for the rolled plates as recorded in Table I. have been multiplied by the factor 3·7 in order to effect a true comparison. This method of plotting is of interest in that it indicates a comparative reduction of the decarburised layer on quenching for the final heat treatment, a result which was confirmed by later work.

Surface decarburisation must be dependent upon many factors, such as the temperature of the furnace, gaseous conditions within the furnace, and the temperature of removal from the furnace. Furnace gases having a high hydrogen or moisture content will undoubtedly bring about a more rapid removal of the carbon than would a dry oxidising gas free from hydrogen.

Heat Treatment.—For the heat-treatment experiments, sections of the rolled plates *X*, *Y*, and *Z*, 2 ft. in length, were reheated in an industrial coke-fired reverberatory furnace to 950° C. and quenched in oil, and then tempered in a lead bath at 450° C.

Influence of Maximum Temperature on Decarburisation.—In view of the relatively small amount of decarburisation in sample *Y*, experiments were carried out in the laboratory to determine whether this result was abnormal or not. Six different specimens were heated in a gas-fired furnace to temperatures ranging from 1,000° to 1,300° C., each one being heated for a period of half-an-hour. After removal from the furnace, and cooling in the air, the depth of decarburisation was measured by means of hardness determinations.

The results of this experiment are given in Fig. 2, from which it will be seen that they fall into line with the data obtained with respect to the practical tests.

The microstructures of the edges of these sections are shown in Figs. 20 to 23 (Plate I.) and completely bear out the hardness determinations. It is seen in the specimen heated to 1,050° C. that the decarburisation as signified by the large amount of ferrite is fairly considerable, becoming greater near to the surface. In the 1,100° C. heat treatment the decarburisation at the surface is greater. In the specimen heated to 1,150° C. the most noticeable features are the increase in grain-size and the presence of ferrite along the grain boundaries only, whilst in that heated to 1,200° C.

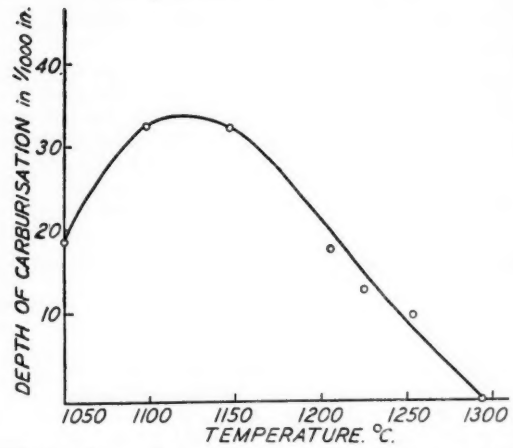

FIG. 2.—Effect of Temperature on Depth of Decarburisation, as determined by the Vickers hardness machine. Constant time of heating, ½ hr.

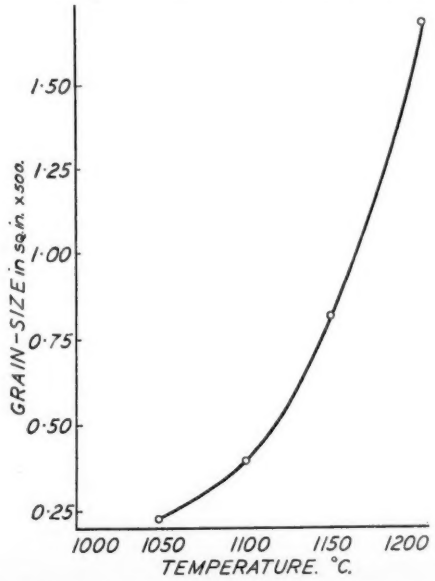

FIG. 3.—Rate of Grain-Growth in Si–Mn Steel with temperature. Constant time of heating, ½ hr.

the complete absence of apparent decarburisation, along with the large increase in grain-size, is very marked.

Two reasons may be assumed for the decrease in decarburisation at elevated temperatures, namely, the formation of a scale, which on account of its fusibility prevents the penetration of gases, and diffusion of carbon from the interior sufficient to compensate for the loss of carbon by its removal from the surface.

The grain-size of these specimens was measured, and the results are plotted in Fig. 3, which shows that the increase in grain growth is a geometrical function of the temperature, the form of curve giving the impression that the limiting value of the grain-size

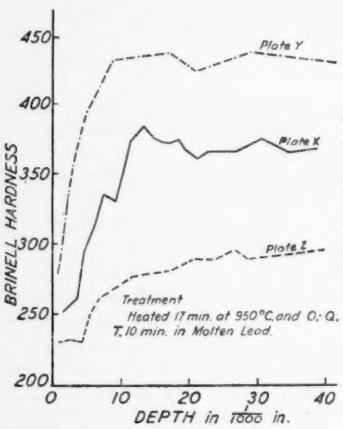

FIG. 4.—Hardness Curves for the Heat-Treated Plates *X*, *Y* and *Z*.

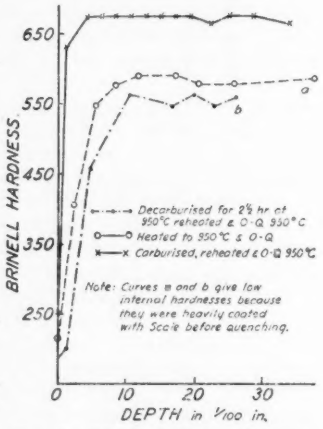

FIG. 5.—Effect of Surface Condition on Hardness of Si-Mn Steel Specimens previously heated and oil-quenched from 950° C.

is a function of the temperature rather than of the time at that temperature.

In this particular steel, as in others, it was observed that on soaking at a high temperature a distinct modification in the state of the carbide was produced. In Fig. 23, for instance, the sorbitic structure occupies a far greater volume than it does in any of the corresponding photomicrographs taken after soaking at temperatures lower than 1,200° C. It would appear that the carbide constituent in some way behaves as a gas, rapidly expanding as the temperature is raised, until a temperature is attained at which the sorbitic structure would occupy the whole field.

It is remarkable that this high-temperature soaking seems to have an influence on the steel even after treatment subsequent to

the original soaking. Provided that the decarburisation is not excessive, thereby bringing about a general reduction in the carbon content of the mass, on oil-hardening and tempering, the samples which were subjected to a high temperature previously invariably gave a harder and more uniform product than those which had not been raised to a high temperature. This effect is clearly indicated in Fig. 4, in which the depth hardness of specimens *X*, *Y*, and *Z* in the form of heat-treated rolled plates are plotted. The decarburisation of *Z* is seen to be excessive, that of *X* is less, whilst *Y* is the least decarburised of the three.

Fig. 5 shows the results of experiments carried out to ascertain the effect of the decarburised layer upon the effectiveness of oil-quenching. Three curves are plotted, representing the depth hardness values of 1-in. cube specimens taken from the original billet. Specimen No. 1 had been surface-carburised prior to quenching, No. 2 had deliberately been decarburised, and No. 3 was a specimen in the original machined state. Curves *a* and *b* indicate that a layer of scale, which formed during heating, together with an underlying decarburised layer, reduce the effectiveness of the quenching medium; moreover, from the fact that, even in the case of the carburised specimen, a small amount of decarburisation but only a thin layer of scale had arisen during heating for oil-hardening, it is apparent that it is the thickness of the scale which plays an important part with respect to the efficiency of quenching.

A further proof that the initial treatment in a large measure affects the final state of the treated plates is shown by Fig. 6, which is self-explanatory. Here it is seen that the three specimens occupy their same relative positions with respect to the degree of hardness in their original unground and ground states.

In order to prove more conclusively whether the carbon content of the surface was a factor of greater importance than the depth of scale in the quenching operations, the scale was removed from the three specimens previously used (Fig. 5), after which they were again quenched from 950° C. in oil. The results of this treatment, given in Fig. 7, certainly indicate that it is the hard tenaceous scale rather than the layer of decarburised iron that is the cause of a loss in the quenching efficiency, and, further, that a non-scaled, heavily decarburised surface gave the most efficient quenching. The actual character of the scale may, however, play a part in the quenching operation, and it may be that a fused or semi-fused scale is more conductive than one more loosely held to the surface. That the character of the scale does change with the temperature was shown by observations made on the original billets, whilst the effect of the character of the furnace atmosphere was demonstrated by an estimation of the ferrous oxide content of scales formed in an oxidising, a neutral

and a reducing atmosphere, values of 70·0, 71·5, and 73·0 per cent., respectively, being obtained. The scale produced in an oxidising atmosphere broke off easily, whilst that formed in a reducing atmosphere was most difficult to remove. Similarly, the part played by different gaseous atmospheres on decarburisation showed but small differences up to temperatures approaching 1,250° C., whatever atmosphere was used. At a temperature of 1,300° C. little or no decarburisation was found on heating in an oxidising, a neutral or a reducing atmosphere.

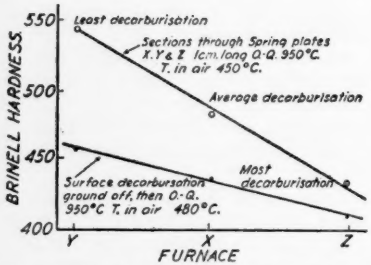

FIG. 6.—Hardness Curves for Heat-Treated Plates rolled from furnaces *X*, *Y* and *Z*.

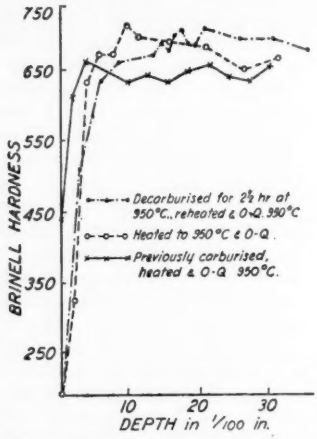

FIG. 7.—Effect of Decarburisation at Surface of Si–Mn Steel Specimens on hardness produced by oil-quenching from 950° C.

Microphotographs taken of specimens *X*, *Y* and *Z* in their three states, namely, reheated billets (air-cooled), as-rolled plates, and in the finished oil-hardened and tempered condition, are illustrated in Figs. 24 to 32 (Plates II. and III.). The interesting feature of these is the diffused state of the carbide in *Y* throughout the whole process of manufacture; this is due undoubtedly to the high temperature attained in the reheating furnace. When the micrographs of *Y* and *Z* in the billet form are compared, it will be observed that *Y*, which was heated to 1,290° C. and only remained in the furnace for 1 hr. 40 min., has a larger grain-size than *Z*, which was heated to 1,260° C., but remained heated for a very prolonged time. This is further evidence of the contention that the grain-size is a function of the temperature rather than of the time, and it is significant that the larger the amount of the

ferrite in the as-rolled plates, the lower is the hardness in the oil-hardened and tempered condition. This illustrates the great importance of obtaining a correct structure prior to hardening. The results of tensometer tests taken on the finished plates are

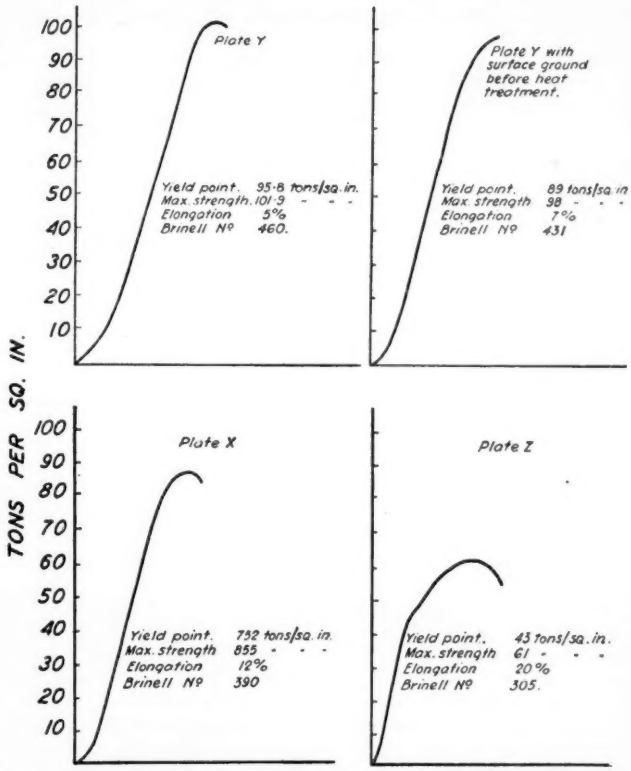

FIG. 8.—Tensometer Tensile Tests on Plates *X*, *Y* and *Z*, O.-Q. 950° C., T. in lead bath 450° C.

shown in Fig. 8. These tests, in confirmation of other data, point to the superiority of *Y* over *X* and, particularly, *Z*.

A cross-sectional piece was cut from plate *Y* after it had been oil-hardened and tempered as a complete plate. Hardness determinations taken across this 3-in. section (the width of the plate) at different positions in the thickness of the plate, are shown

and a reducing atmosphere, values of 70·0, 71·5, and 73·0 per cent., respectively, being obtained. The scale produced in an oxidising atmosphere broke off easily, whilst that formed in a reducing atmosphere was most difficult to remove. Similarly, the part played by different gaseous atmospheres on decarburisation showed but small differences up to temperatures approaching 1,250° C., whatever atmosphere was used. At a temperature of 1,300° C. little or no decarburisation was found on heating in an oxidising, a neutral or a reducing atmosphere.

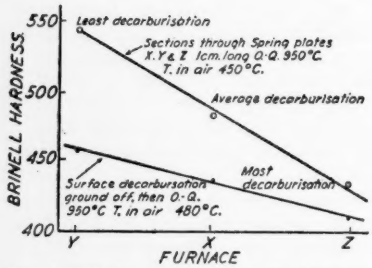

FIG. 6.—Hardness Curves for Heat-Treated Plates rolled from furnaces *X*, *Y* and *Z*.

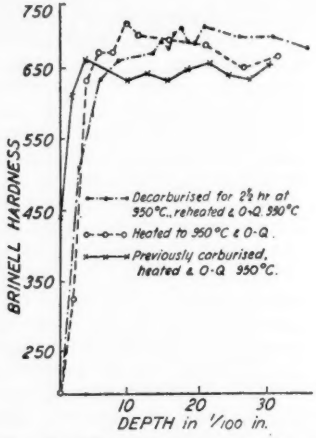

FIG. 7.—Effect of Decarburisation at Surface of Si–Mn Steel Specimens on hardness produced by oil-quenching from 950° C.

Microphotographs taken of specimens *X*, *Y* and *Z* in their three states, namely, reheated billets (air-cooled), as-rolled plates, and in the finished oil-hardened and tempered condition, are illustrated in Figs. 24 to 32 (Plates II. and III.). The interesting feature of these is the diffused state of the carbide in *Y* throughout the whole process of manufacture; this is due undoubtedly to the high temperature attained in the reheating furnace. When the micrographs of *Y* and *Z* in the billet form are compared, it will be observed that *Y*, which was heated to 1,290° C. and only remained in the furnace for 1 hr. 40 min., has a larger grain-size than *Z*, which was heated to 1,260° C., but remained heated for a very prolonged time. This is further evidence of the contention that the grain-size is a function of the temperature rather than of the time, and it is significant that the larger the amount of the

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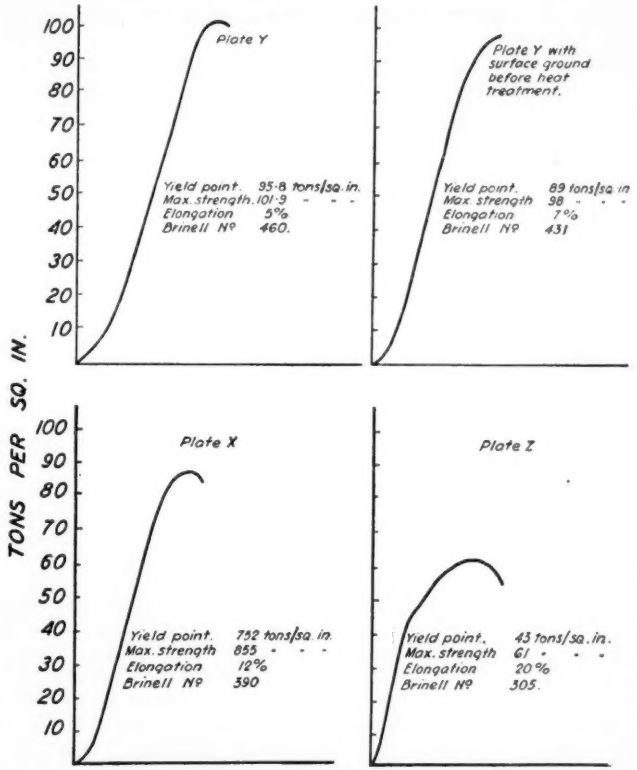

FIG. 8.—Tensometer Tensile Tests on Plates *X*, *Y* and *Z*, O.-Q. 950° C., T. in lead bath 450° C.

shown in Fig. 8. These tests, in confirmation of other data, point to the superiority of *Y* over *X* and, particularly, *Z*.

A cross-sectional piece was cut from plate *Y* after it had been oil-hardened and tempered as a complete plate. Hardness determinations taken across this 3-in. section (the width of the plate) at different positions in the thickness of the plate, are shown

in Fig. 9. The results obtained were contrary to what would be expected, and it will be seen that it is only along the extreme edge of the original plate that an effective hardening has been brought about. The inference to be drawn from these curves is that spring plates as normally hardened are extremely non-uniform, the centres being considerably softer than the edges.

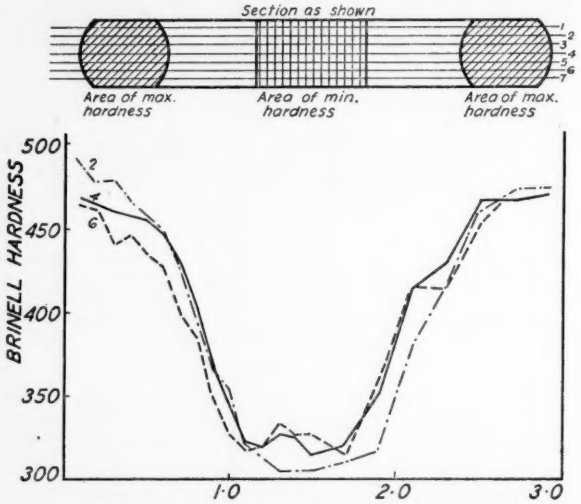

FIG. 9.—Hardness Chart of Heat-Treated Si–Mn Spring Plate.

These results suggested that the quenching temperature might not have been sufficiently high to promote homogeneity in the structure. Experiments were then carried out as follows : Several plates were heated to different temperatures prior to quenching in oil ; they were then tempered, and the hardness values at positions *B* and *A* determined. These values are plotted in Fig. 10, from which it is seen that the marked differences in hardness between positions *A* and *B* are only avoided by quenching from a temperature above 1,050° C. Between 950° C. and 1,050° C. the curve for position *A* gradually approaches that of *B*, finally joining it above 1,050° C.

It was thought that the critical changes of the silico-manganese steel might be affected by varying the initial temperatures, but thermal curves taken from temperatures varying from 900° C. to 1,300° C. clearly showed no change in the transformation point, the critical changes being unaffected by the initial temperature.

The effect upon the hardness caused by varying times of

soaking is depicted in Fig. 11. Whilst these results are of interest, it is obvious that further work is required in order to give a satisfactory explanation of the peculiar minimum at 20 min.

Referring again to Fig. 10, the results embodied in this graph provide further confirmation of the suggestion made earlier, namely, that a high temperature promotes a greater diffusion and

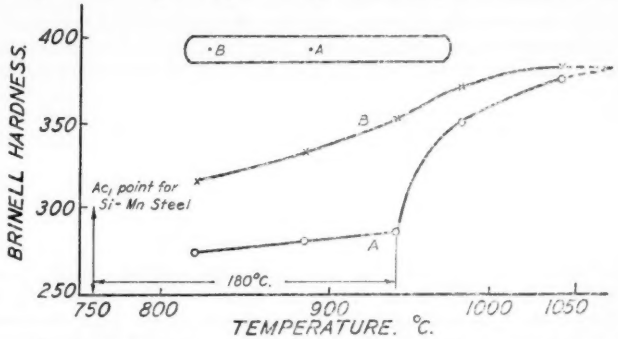

FIG. 10.—Hardness Curves for Si-Mn Steel at positions *A* and *B* indicated.

better distribution of the carbon, so that whilst the normal transformations may occur on cooling, this disperse state will exist even after the completion of the critical changes. It is well known that the degree of dispersion of the carbide particles plays an important part in the tensile properties of a steel.

A Comparison of Silico-Manganese, Chromium-Vanadium and Plain Carbon Spring Steels.—For the purpose of this investigation three billets were selected of the following compositions: A plain carbon steel containing 0·6 per cent. of carbon; a chromium-vanadium steel containing 0·52 per cent. of carbon, 1·27 per cent.

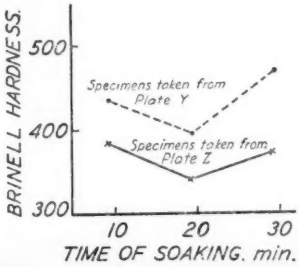

FIG. 11.—Relation between Hardness of Heat-Treated Specimens of Si-Mn Steel and Time of Soaking. Temperature 950° C.; O.-Q., T. 20 min. 450° C.

of chromium, and 0·25 per cent. of vanadium ; and a silico-manganese steel containing 0·45 per cent. of carbon, 2·02 per cent. of silicon, and 0·76 per cent. of manganese.

It was arranged that these billets should be put through the usual rolling and treatment processes by three different manufacturers who specialised in the manufacture of spring plates.

With a view to ascertaining the degree of decarburisation brought about in the different processes of manufacture, each billet was machined over a third of its length on the four surfaces, as indicated in Fig. 12. *A* and *B* in this sketch refer to the positions

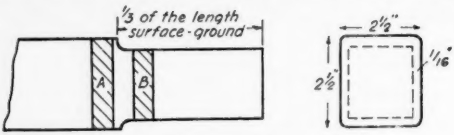

Fig. 12.—Diagram of Original Billet.

from which sections were cut for micro-examination. Since these sections were within 3 in. of one another, it could reasonably be assumed that no difference in temperature would exist between them during any time in the heating processes. The billets were weighed before being placed in the reheating furnace, and likewise the finished plates were weighed after rolling, thus allowing the loss in weight to be measured after each process.

The losses in weight along with other data are recorded in Table II., from which it is observed that firm *B*, using a gas-fired

Table II.

Firm.	Type of Furnace.	Max. Temp. reached. ° C.	Kind of Steel.	Time in Furnace. Min.	Original Weight of Billet.	Final Weight of Billet.	Loss. %
A.	Coal-fired with temp. greater at back than at front. No smoke. One-high mill.	1250 to 1280	C	28½	68½ lb.	67 lb.	2
			Cr-V	34½	74½ lb.	73 lb.	2
			Si-Mn	38	75 lb.	74 lb.	1·5
B.	Gas-fired, using a coke-bed, positive pressure, air forced through coke-bed. One-high mill	1060	C	56	68 lb. 10 oz.	68 lb. 5 oz.	0·5
			Cr-V	61	73 lb. 4 oz.	72 lb. 14 oz.	0·5
			Si-Mn	65	73 lb. 3 oz.	72 lb. 14 oz.	0·5
D.	Fired with producer gas, luminous flame. No smoke. No coal used. Two-high mill. Plates stacked	1230	C	28	68 lb.	67 lb.	1·33
			Cr-V	31	71 lb.	70 lb.	1·33
			Si-Mn	32	75½ lb.	75 lb.	0·7

furnace with a coke bed, produced the minimum amount of scaling. Generally speaking, the silico-manganese billet scaled the least.

Table III. gives details of the practical operations with respect to temperatures and times taken over the different processes. An examination of the surfaces after reheating for rolling revealed in the case of the plain carbon and the chromium-vanadium steels, a very adherent and protective scale, whilst on the silico-manganese billets the scale was of a less adherent nature. Definite penetration of oxide into the ferrite matrix was observed in the unmachined silico-manganese billet; in the machined section this was less pronounced. This is depicted in Figs. 33 and 34 (Plate III.). The microstructures of the reheated billets from furnace *B* are

TABLE III.

Firm.	Steel.	Time of Heating. Min.	Time to Rolls. Sec.	Time taken in Rolling.	Temperature at Various Stages. °C.			No of Passes.
					In Furnace.	After 1st Pass.	Finishing.	
A.	C	28½	15	2 min. 17 sec.	1250 to 1280	1206	1030	7
	Cr-V	34½				1200	1024	
	Si-Mn	38				1260	1060	
B.	C	56	15	2 min. 20 sec.	1060	1028	885	9
	Cr-V	61				980	915	
	Si-Mn	65				1000	858	
D.	C	28	10	..	1230	1195	1035	11
	Cr-V	31				1170	1025	
	Si-Mn	32				1190	1010	

shown in Figs. 36 to 41 (Plate IV.); these include the decarburised surfaces. The coarse grain structure of the plain carbon steel, as compared with the smaller grain structure of the silico-manganese steel, along with the finely distributed sorbitic structure of the chromium-vanadium steel, are the chief points to be noted.

Figs. 42 to 47 (Plate V.) represent the structures of billets from furnace *D*. The high temperature of this furnace has brought about a uniformity in grain-size in the three types of steel.

A comparison between the structures of the machined and unmachined parts indicates that machining is only effective when reheating is carried out at a low temperature. The effect of machining is, however, more pronounced when the rolled plates

are examined. The series of micrographs, Figs. 48 to 53 (Plate VI.), from furnace *B*, and 54 to 59 (Plate VII.), from furnace *D*, are given to illustrate not only the effect of machining, but also the effect of the finishing temperature of rolling. Owing to the fineness of structure of the chromium-vanadium steel, it is more difficult to judge the extent of decarburisation than it is in the other steels. The conclusion may be drawn that, provided that low temperatures are employed throughout the process, machining the billets does reduce the decarburised layer in the rolled plates, but where a high temperature is attained the difference is but slight.

The depth of the decarburised layer as measured under the microscope for all the materials dealt with is given in Table IV. Whilst, as has been stated previously, the depth as found by hardness measurements is invariably greater, these results may be regarded as being truly comparative.

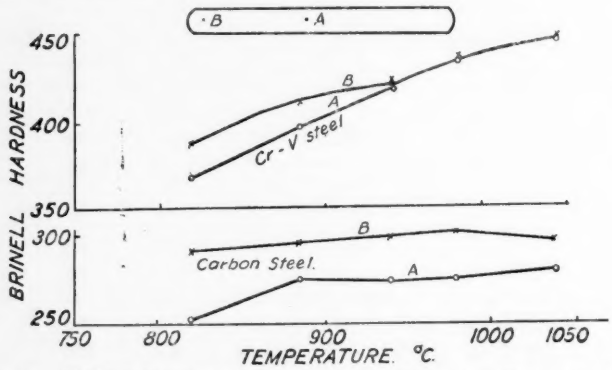

Fig. 13.—Hardness Curves for Carbon and Cr–V Steels at positions *A* and *B* indicated.

In order to ascertain whether a plain carbon and a chromium-vanadium steel behaved in a manner similar to a silico-manganese steel, with respect to non-uniformity of hardening on quenching, a series of experiments was carried out on precisely the same lines ; 6-in. sections cut from a rolled spring plate, after hardening by quenching in oil from different temperatures, were tested for hardness at the two positions *A* and *B*, Fig. 13. It is seen from these graphs that in the case of the plain carbon steel, the hardness at *A* shows no sign of approaching that at *B*, even when the quenching temperature has been raised to 1,050° C., whereas for the chromium-vanadium steel the two branches coincide at a temperature of 950° C. For this reason it is to be expected that a

TABLE IV.

Furnace.	Kind of Steel Used.	Time of Heating. Min.	Size of Plate Rolled. In.	Temperature reached in Furnace. ° C.	Finishing Temperature of Rolling. ° C.	Depth of Decarburisation, in thousands of an inch.				Heat-Treated Plates.	No. of Passes.
						Billets.		Rolled Plates.			
						Not Machined. (Visible	Machined. Depth	Not Machined. Measured.)	Machined.		
..	Original billets C	..	..	..	..	12					
	Cr–V	..	..	..	..	18					
	Si–Mn	..	..	..	..	20					
A.	C	28½	2¼ × ⅜	1250 to 1280	1030	20	18	8	8	..	7
	Cr–V	34½			1024	18	18	4	Not measurable		
	Si–Mn	38			1060	30	20	7	4		
B.	C	56	3 × ⅜	1060	885	16	8	5	Not measurable	..	9
	Cr–V	61			915	20	2	3			
	Si–Mn	65			858	22	12	4			
D.	C	28	3 × ⅜	1230	1035	22	15	5	4	..	11
	Cr–V	31			1025	16	15	4	2		
	Si–Mn	32			1010	25	16	6	4		
Heat Treatment: 6-in. lengths of plates rolled from furnaces *A*, *B* and *D* were used. They were heated for 30 min. at 980° C., oil-quenched, and then tempered for 1 hr. at 550° C. in air.										C 5 Cr–V 3 Si–Mn 10	

chromium-vanadium steel will be the most homogeneous of all in its final heat-treated condition.

Micrographs taken of the quenched and tempered structures produced by quenching the 6-in. lengths of silico-manganese, chromium-vanadium and plain carbon steel specimens from each of the temperatures 820° C., 885° C., 940 °C., 980° C. and 1,040° C., show that the structures of the silico-manganese and carbon steels vary appreciably with the temperature, but the chromium-vanadium steel seems to be unaffected. The chromium-vanadium specimens, even when quenched from 1,040° C., had a very fine martensitic structure, but the silico-manganese steel required a temperature of 1,050° C. to produce complete solution and the best martensitic structure. Naturally, grain growth at this temperature is considerable.

The Influence of Rolling on the Properties of the As-Rolled Plate.—It was noticed that the greater the reduction per pass, the greater became the hardness of the as-rolled material. In Table IV.

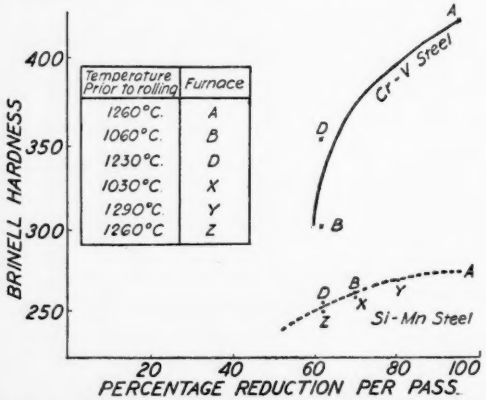

Fig. 14.—Relation between Percentage Reduction and Hardness of spring plates in the as-rolled condition.

it is seen that for the plates from furnace *A*, a reduction from $2\frac{1}{2}$ in. square to a plate $2\frac{1}{2}$ in. $\times$ $\frac{3}{8}$ in. was made in seven passes, whereas for those from furnace *D*, the reduction from $2\frac{1}{2}$ in. square to 3 in. $\times$ $\frac{3}{8}$ in. took place in eleven passes. On plotting all such available results for the silico-manganese and chromium-vanadium steels, it was observed (Fig. 14) that as the percentage reduction per pass for hot-rolling increased, so, likewise, did the hardness values; in the case of the chromium-vanadium steel from furnace *A* this increase amounted to more than 33 per cent.

X. *Z.* *Y.*

FIG. 19.—Sections of Billets.
SI–MN STEEL. × 50.

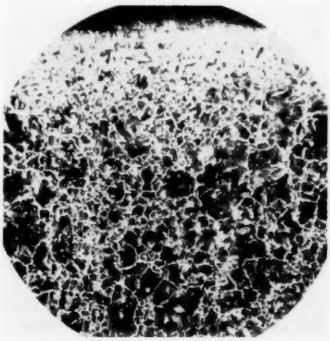

FIG. 20.—½ hr. at 1,050 C., A.-C.

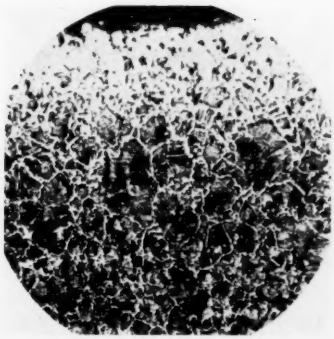

FIG. 21.—½ hr. at 1,100 C., A.-C.

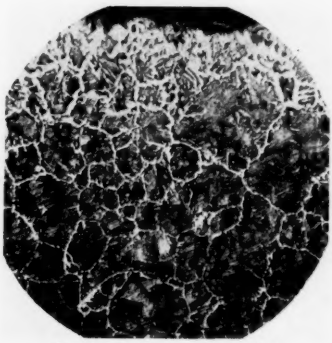

FIG. 22.—½ hr. at 1,150 C., A.-C.

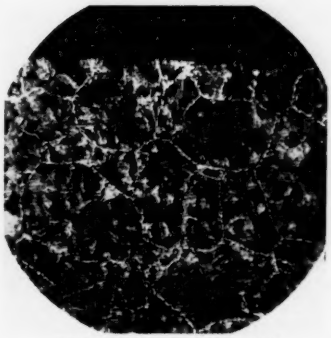

FIG. 23.—½ hr. at 1,200 C., A.-C.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Andrew and Richardson.*
To face p. 144.

STEEL *X*.

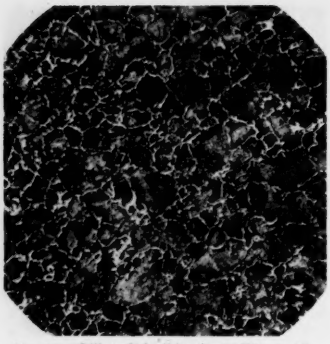

FIG. 24.—Billet. Brinell hardness, 275. × 50.

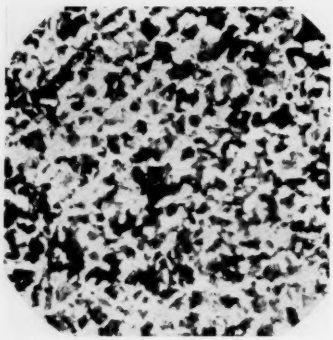

FIG. 25.—Plate, as-rolled. Brinell hardness, 250. × 250.

FIG. 26.—Plate, Q. and T. Brinell hardness, 390. × 1,000.

STEEL *Y*.

FIG. 27.—Billet. Brinell hardness, 280. × 50.

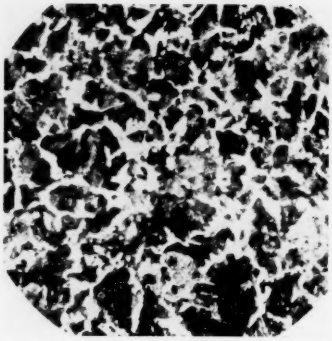

FIG. 28.—Plate, as-rolled. Brinell hardness, 270. × 250.

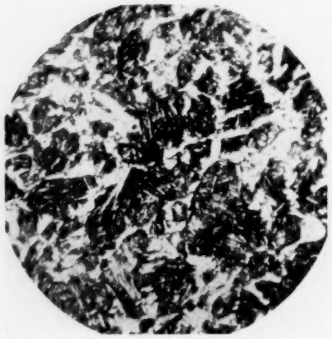

FIG. 29.—Plate, Q. and T. Brinell hardness, 430. × 1,000.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Andrew and Richardson.*

STEEL *Z*.

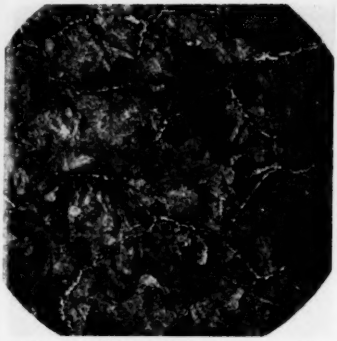

FIG. 30.—Billet. Brinell hardness, 283. × 50.

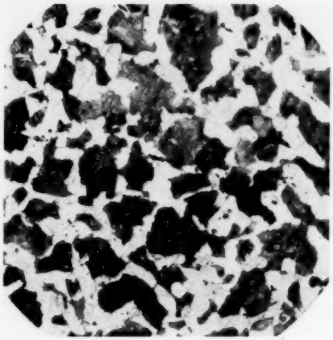

FIG. 31.—Plate, as-rolled. Brinell hardness, 240. × 250.

FIG. 32.—Plate, Q. and T. Brinell hardness, 305. × 1000.

SI–MN STEEL. × 250.

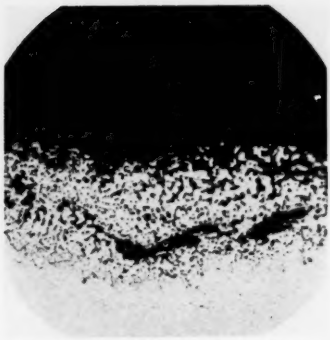

FIG. 33.—Unmachined. Oxide penetration. Unetched.

FIG. 34.—Machined. Less oxide penetration. Unetched.

STEEL *X*.

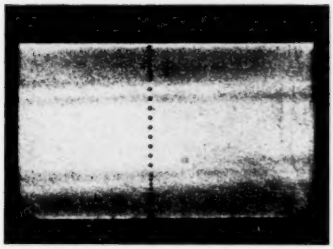

FIG. 35.—Section. Etched with 2% alcoholic HNO_3. × 4.

(Illustrations reduced to four-fifths linear in reproduction.)

[*Andrew and Richardson.*

BILLETS FROM FURNACE *B*. × 50.

UNMACHINED. MACHINED.

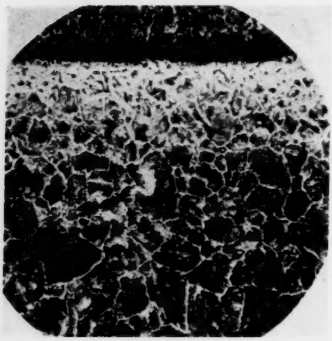

FIG. 36.—Carbon Steel, *C*8.

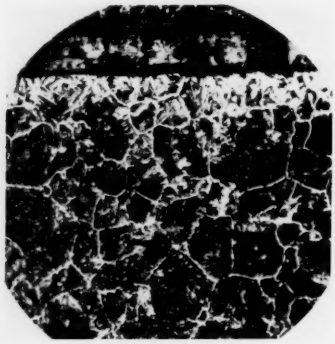

FIG. 37.—Carbon Steel, *C*8.

FIG. 38.—Cr–V Steel, *V*10.

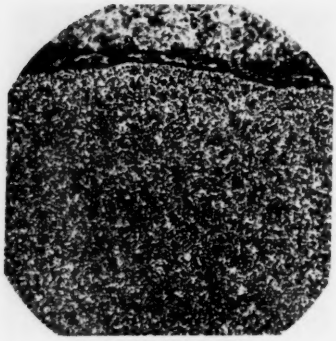

FIG. 39.—Cr–V Steel, *V*10.

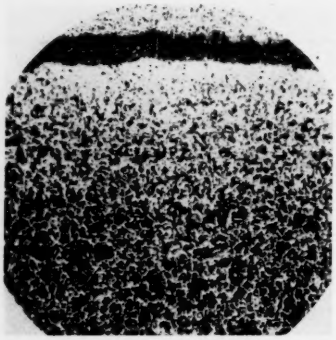

FIG. 40.—Si–Mn Steel, *S*12.

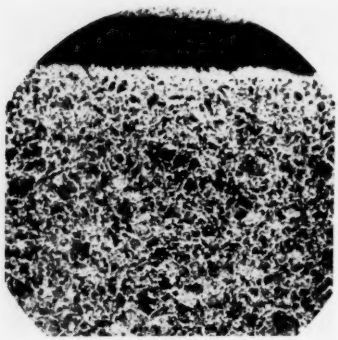

FIG. 41.—Si–Mn Steel, *S*12.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Andrew and Richardson.*

BILLETS FROM FURNACE *D*. × 50.

UNMACHINED. MACHINED.

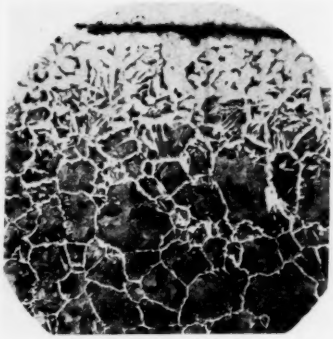

FIG. 42.—Carbon Steel, *C*19.

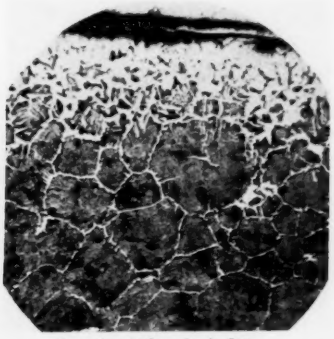

FIG. 43.—Carbon Steel, *C*19.

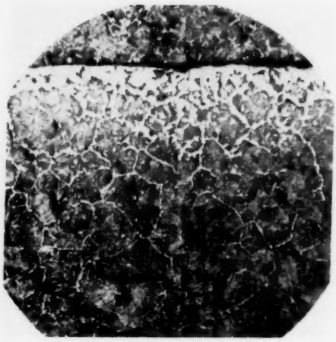

FIG. 44.—Cr–V Steel, *V*21.

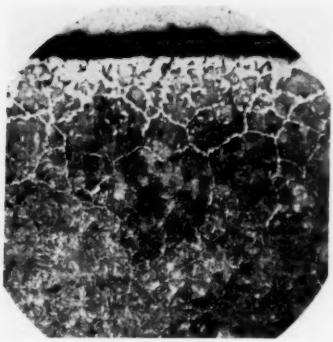

FIG. 45.—Cr–V Steel, *V*21.

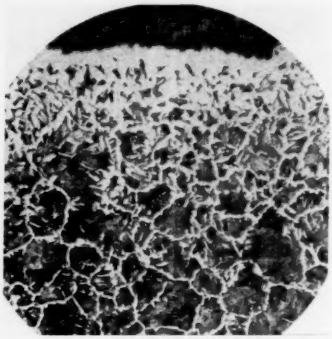

FIG. 46.—Si–Mn Steel, *S*23.

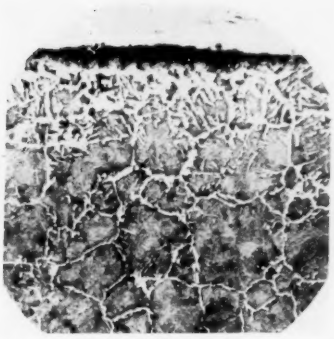

FIG. 47.—Si–Mn Steel, *S*23.

(Micrographs reduced to four-fifths linear in reproduction.)

Andrew and Richardson.

ROLLED PLATES FROM FURNACE *B*. × 200.

UNMACHINED END. MACHINED END.

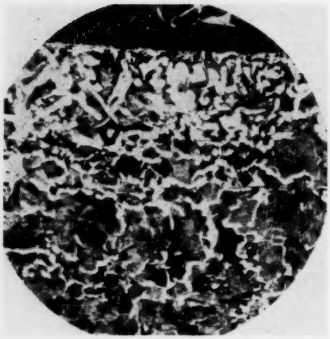

FIG. 48.—Carbon Steel, *C*7.

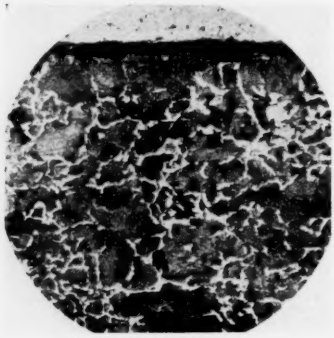

FIG. 49.—Carbon Steel, *C*7.

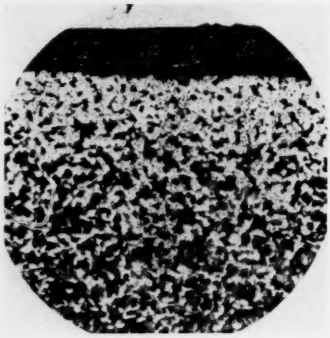

FIG. 50.—Cr-V Steel, *V*9.

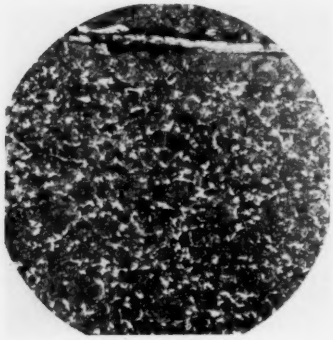

FIG. 51.—Cr-V Steel, *V*9.

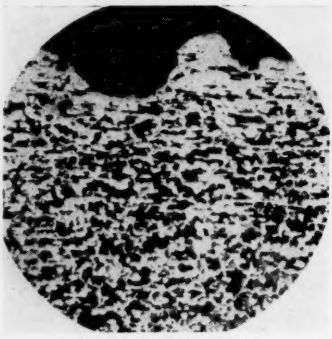

FIG. 52.—Si-Mn Steel, *S*11.

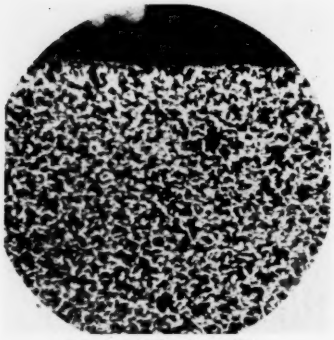

FIG. 53.—Si-Mn Steel, *S*11.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Andrew and Richardson.*

ROLLED PLATES FROM FURNACE *D*. × 200.

UNMACHINED END. MACHINED END.

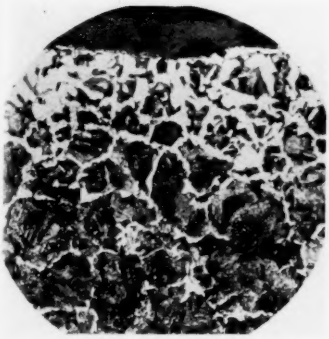

FIG. 54.—Carbon Steel, *C*20.

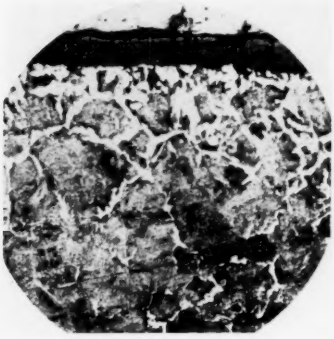

FIG. 55.—Carbon Steel, *C*20.

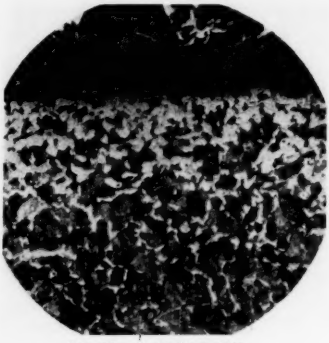

FIG. 56.—Cr–V Steel, *V*22.

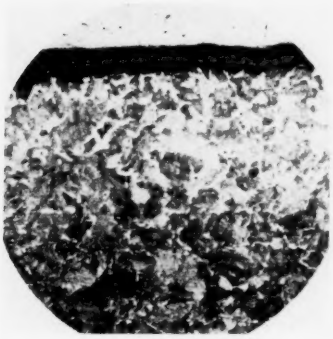

FIG. 57.—Cr–V Steel, *V*22.

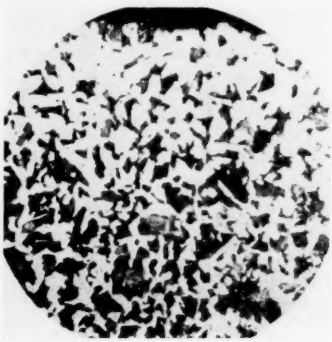

FIG. 58.—Si–Mn Steel, *S*24.

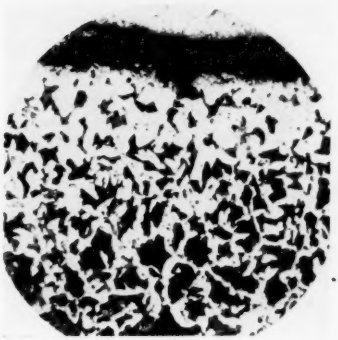

FIG. 59.—Si–Mn Steel, *S*24.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Andrew and Richardson.*

FIG. 60.—Si-Mn Steel, machined side. O.-Q. and T. × 450.

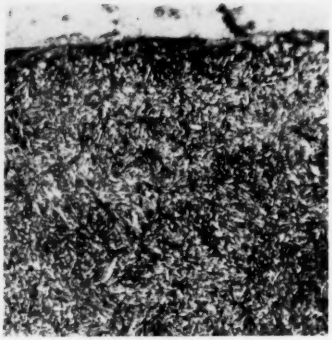

FIG. 61.—Si-Mn Steel, machined side. W.-Q. and T. × 450.

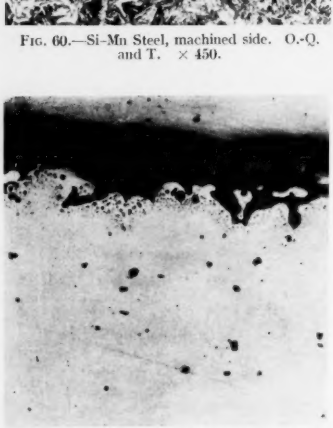

FIG. 62.—Typical Oxidation of all machined Si-Mn steels. × 240.

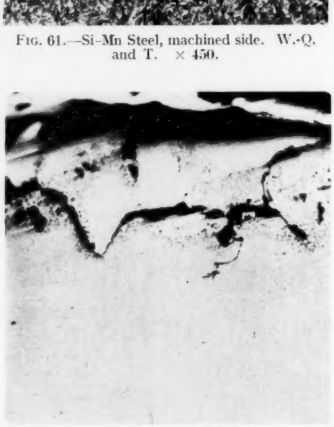

FIG. 63.—Max. Oxide Penetration in unmachined Si-Mn steel. × 240.

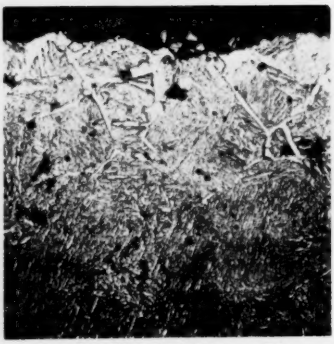

FIG. 64.—Si-Mn Steel, W.-Q. × 240.

FIG. 65.—Si-Mn Steel, O.-Q. × 240.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Andrew and Richardson.*

[*To face p.* 145.

This was confirmed by the microstructure, that of specimen *A* (chromium-vanadium) being of a martensitic type with a complete absence of ferrite, whilst that of *B* was a typical ferrite-pearlite structure.

From these results it is evident that the degree of reduction per pass in hot-rolling is a factor to be taken into account. It would appear that a large reduction per pass is responsible for producing a uniform structure in the plate, and thereby facilitating solution of the carbide in the final quenching operation.

With regard to the silico-manganese series, it will be noted that specimen *Y*, taken from the earlier work, occupies a high position in the hardness curve, and gave the best results on the finished plates. That these results are due to the degree of reduction and not to the finishing or initial temperature was substantiated by

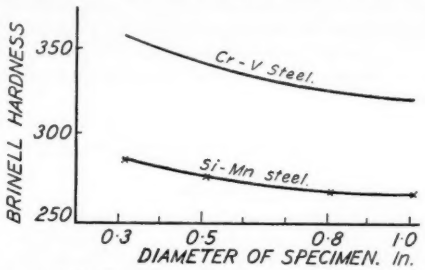

FIG. 15.—Influence of Air-Cooling on Hardness of Cr–V and Si–Mn Steels, A.-C. from 1,200° C.

experiments relating the hardness to the initial temperature (Fig. 15), which shows that the differences produced on air-cooling specimens of varying size from 1,200° C. has but a slight effect on the final hardness. The same effect was observed on air-cooling from 1,100° C.

Additional Experiments.—Some tests were carried out in a modern industrial oil-fired furnace, in which 6-in. lengths of a silico-manganese steel containing carbon 0·50 per cent., silicon 1·80 per cent., and manganese 0·80 per cent., were heated. One side of each of these plates was machined to a depth of $\frac{1}{16}$ in. Two specimens were heated to 1,000° C., and one was quenched in oil and the other in water; two further specimens were heated to 900° C., and, as before, one was quenched in oil and one in water. Hardness depth curves gave the following results:

Quenching Temp.	Method of Cooling.	Tempering Temp.	Surface Hardness— Machined.	Unmachined.
1,000° C.	Oil.	300° C.	493	325
1,000° C.	Water.	300° C.	510	440
900° C.	Oil.	450° C.	330	270
900° C.	Water.	450° C.	348	350

These results show clearly that the machined surfaces on treatment give a greater hardness value than the unmachined.

A comparison of the microstructure of the specimens quenched in oil and water from 900° C., and then tempered at 450° C., is interesting. On comparing the oil-quenched, Fig. 60 (Plate VIII.), with the water-quenched machined specimens, Fig. 61, the great difference lies in the finer structure of the latter, due in all probability to the greater deformation of structure caused by the more drastic method of cooling. The unmachined surfaces in both cases showed a coarser structure containing more ferrite.

The actual degree of oxide penetration at the surfaces was the same in the machined and unmachined surfaces (Figs. 62 and 63). The finer structure obtained on water-quenching, as compared with oil-quenching, is shown by Fig. 64 (quenched in water) and Fig. 65 (quenched in oil), in which it will be seen that the amount of ferrite on and near to the surface is equal, confirming the fact that even at 1,000° C. complete homogeneity in a decarburised layer is not possible, although the internal structure is more refined by water-quenching.

Hardness-depth curves taken right across the thickness of a rolled plate, in the as-rolled condition, are given in Fig. 16.

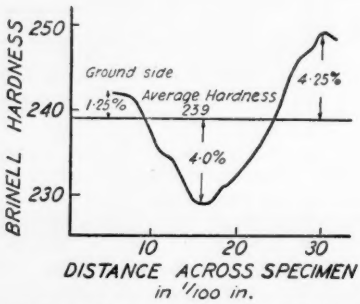

FIG. 16.—Hardness Curve across Centre of Specimen No. 4.

This clearly shows that the middle portions, even in the as-rolled state, are softer than the edges. On oil-quenching from 1,000° C., Fig. 17, this effect is further magnified. These curves are typical of silico-manganese steels, and were confirmed by further experiments, the results of which are plotted in Fig. 18. The interesting feature of these curves is that the maxima and minima in the as-rolled condition correspond with those in the as-quenched state.

A section, etched with 2 per cent. nitric acid in alcohol, across the thickness, is shown in Fig. 35 (Plate III.). The dark patches correspond to the maxima in the hardness curve, and an X-ray

examination indicated that even in the as-rolled condition the dark-etching portions were associated with a greater degree of atomic distortion.

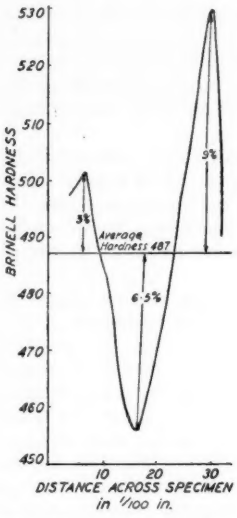

FIG. 17. — Hardness Curve across Centre of Specimen No. 5; 10 min. at 1,000° C., O.-Q., T. 1 hr. at 300° C.

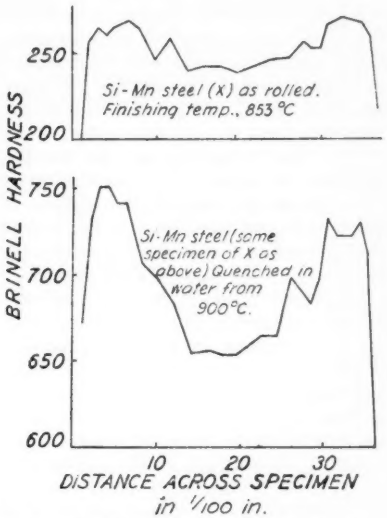

FIG. 18.—Hardness Curves of Si-Mn Steel.

These results strongly emphasise the fact that the final structure and properties of the heated plate depend very largely on the structure prior to the final heat-treatment operation, and suggest that the best results are attained by a high soaking temperature of the billet, which promotes homogeneity, followed by drastic reductions in the rolling-mill to break down the coarse structure.

CONCLUSIONS.

(1) Of the various furnaces employed in the practical operations, type *B* seems to be the best with regard to scaling and decarburisation, but *Y* appears to be superior in producing a good finished plate, as regards decarburisation, structure and hardness. Whatever may be the extent of decarburisation on the billets immediately before rolling, this will be considerably increased in the course of rolling, although this operation only takes two or three minutes.

(2) The higher the temperature in the furnace prior to rolling, the greater is the grain-size of the billet produced and the better are the properties of the finished plate.

(3) Large initial grain-size, coupled with a heavy reduction per pass, results in a more even structure of the finished plates. When the reduction per pass exceeds 80 per cent., the whole of the plate will have the same structure. The lower the temperature and the lower the reduction per pass, the more non-uniform the as-rolled plates seem to be, the centre portion being structurally different from the outside areas.

(4) The properties of the finished plates are influenced by those of the as-rolled plates, the latter appearing to depend more than anything upon (*a*) the highest temperature reached and the grain-size produced, and (*b*) the reduction per pass. Evidence for this is seen in the similarity of contour of hardness-depth curves for the as-rolled and finished states.

(5) Heavy scale on the surface of spring plates plays an important part in the efficiency of the quenching operation.

(6) Contrary to expectations, a specimen with the greatest depth of decarburisation and only slightly scaled, becomes hardened to a greater degree than one only slightly decarburised, indicating that a layer of ferrite on the surface is instrumental in causing a more thorough quenching than a similar steel surface, possibly on account of the higher conductivity of the free ferrite.

(7) Silico-manganese steel seems to be inferior to plain carbon and chromium-vanadium steels for the following reasons : (*a*) It is always more decarburised than the other two, owing to the scale being more friable and of a less protective nature ; (*b*) the steel is very susceptible to mass effect. Once the length of a spring plate exceeds 6 in., the hardnesses at positions *A* and *B* do not coincide until a temperature of quenching approaching 1,050° C. has been reached ; (*c*) the structure of the hardened spring plates is appreciably altered by (1) the temperature reached before rolling begins, and (2) the temperature from which quenching takes place ; (*d*) the scale seems very friable, easily breaking off and leaving a rough and jagged surface. Such a surface, along with intercrystalline penetration of oxide, has been shown to be weak ; and (*e*) there is always some penetration of oxide in the surface layer and along the grain boundaries, whatever the temperature to which it has been heated.

(8) Chromium-vanadium steel seems to be decidedly superior, as (*a*) under identical conditions it decarburises and scales the least. The scale produced, however, protects the surface, which is not jagged like that of silico-manganese steel ; (*b*) penetration of scale along the grain boundaries does not take place ; and (*c*) it is not greatly influenced by mass effect, nor does the temperature of quenching seem to influence the final structure. In no

case has the structure of quenched specimens been observed to be coarse, as with carbon and silico-manganese steels.

(9) In the case of the plate from furnace *A*, the high temperature prior to rolling and the heavy reduction per pass have produced a hardness of 400 Brinell and a martensitic structure.

The authors wish to acknowledge the valuable assistance so willingly given by Mr. G. A. de Belin and Mr. R. T. Percival, B.Met., in connection with the experimental work embodied in this paper.

DISCUSSION.

Dr. M. L. Becker (Teddington) said the paper by Professor Andrew and Mr. Richardson seemed to form a most valuable continuation, or rather amplification, of one section of the work on the fatigue of springs in which Dr. Hankins and he were engaged at the National Physical Laboratory, and on which they had had the privilege to report to the Institute from time to time.

At the time when they published their results relating to the effect of a decarburised surface layer on the fatigue properties of springs and forgings, several people expressed considerable doubt as to the possibility of applying the results in practice. They were therefore extremely gratified to know that the Committee of the Sheffield Spring Makers was giving the matter such careful consideration and they would like to congratulate the authors and the Committee upon the success of the investigation and upon the very useful practical data now disclosed.

No fatigue tests were quoted in the paper, and it might therefore not be out of place to recall that quite a thin decarburised surface layer on springs might account for a loss of nearly half the intrinsic fatigue resistance of the material. Evidence had also been obtained that the less the depth of decarburisation, below a certain limit, the higher was the fatigue resistance. It must therefore be apparent that any reduction in decarburisation which could be effected by control of the furnace atmosphere and methods of manufacture was likely to be reflected in improved properties, and for that reason the authors' results would commend themselves to all concerned in the manufacture of springs and other machine parts required to withstand relatively high repeated stresses in service.

Several points of detail in the paper appeared to call for comment. It was stated at the beginning that "the microstructure is not a correct criterion of the amount of decarburisation, the figure given by hardness determinations being considerably greater." To a certain extent he could confirm that observation, but he had generally attributed the slight differences observed to some error in correlation between the two sets of measurements. The larger differences reported in the present paper, however, suggested that there was some fundamental difference, and he would like to know if the authors could offer any explanation as to why that should be so. Incidentally, a good deal depended on the method employed for the hardness analysis. One of the most convenient methods was to machine a plane slightly inclined to the surface and to determine the pyramid hardness, using a low load, at various points along the plane.

There were other methods, however, and it would add to the value of the data if details regarding the method of hardness testing could be included in the paper.

Figs. 20 to 23 illustrated a most interesting conclusion, namely, that the higher the furnace temperature the less was the degree of surface decarburisation. The increase in grain-size of the body material was shown in Fig. 23, and the authors called attention to the decrease in the quantity of free ferrite which accompanied the increase in the temperature of treatment. Did not the authors think that, in common with sorbitic structures in general, it was merely the quantity of ferrite at the grain boundaries which diminished as the grains increased in size? A simple explanation was that with the larger grain-size the α-iron was precluded from diffusing from the centre of the grain to the outside in the short time available during cooling, and he would therefore challenge the statement made in the paper: "It would appear that the carbide constituent in some way behaves as a gas, rapidly expanding as the temperature is raised, until a temperature is attained at which the sorbitic structure would occupy the whole field." That was quite new to him, and he thought it was necessary to have a little more information on the subject.

The authors concluded that heavy scale on the surface of spring plates played an important part in the efficiency of the quenching operation. That was undoubtedly true, but it seemed that the effect of large grain-size in promoting deep hardening characteristics had been rather overlooked, and, in his opinion, some of the effects attributed to the presence or absence of scale might to some extent have been brought about by the differing grain-size induced by previous treatment.

Really the only serious criticism of the results seemed to him to lie in the distinctly poor uniformity in hardness which was obtained with silico-manganese steel. Professor Andrew had referred to it as being quite satisfactory, but, judging by some of the figures given, he (Dr. Becker) failed to see that the uniformity was satisfactory. The uniformity was certainly not so good as was obtained with the particular steels used in the research with which he had been connected. Possibly the different behaviour was due to composition, both the carbon and the manganese contents being lower than in the case of his own steel, which oil-quenched fairly uniformly. Perhaps steel makers would discuss that point, since the authors' results scarcely did justice to a type of material usually regarded as reliable in that respect.

Actually, a reference to Fig. 9 indicated that the rate of cooling obtained on oil-quenching the silico-manganese steel was insufficiently rapid to bring about complete hardening. In other words, the rate of cooling obtained by oil-quenching was too

near the critical rate for the particular steel. The results shown in Fig. 10 appeared to confirm that. There, although the actual cooling rate was probably very little altered, the increasing quenching temperature brought about grain-growth and possibly other changes which definitely retarded the critical speed of quenching. The margin between the critical rate and the rate actually employed was thus increased as the temperature increased, and that would account for the greater uniformity obtained by quenching from higher temperatures. The margin, however, was too small in practice, and he could not agree that the use of an excessively high quenching temperature was the right way to obtain more uniform hardening. On the other hand, water-quenching gave a more rapid rate of cooling, and for that reason the particular silico-manganese steel used by the authors seemed to be more suitable for water-quenching than for oil-quenching. He did not know whether spring makers would bear that out or not.

Oil-quenching sufficed to give quite a uniform hardness to the chromium-vanadium steel, and that he could confirm from his own observations, as well as the important fact that chromium-vanadium steel was less sensitive to decarburising conditions than either carbon or silico-manganese steels.

It might sound as though he had made a great many criticisms, but that did not represent his real view of the paper as a whole ; Dr. Hankins and he felt in substantial agreement with most of what was in the paper and would be able, he hoped, to make use of it in their future work.

Dr. T. SWINDEN (Sheffield) said that this work was a useful addition to that carried out by other investigators concerning the relative merits of carbon, silico-manganese and chromium-vanadium steels for springs. One should, however, emphasise, he thought, that the methods relied upon in this investigation were micro-examination and hardness tests. The conclusions reached should be read in conjunction with that fact. His own experience, extending over many years, would agree with the conclusions of the authors in regard to the superiority of chromium-vanadium steel over silico-manganese steel. Quite apart from the relative resistance to scaling and decarburisation and harden-ability, it was readily demonstrable that chromium-vanadium steel had a higher elastic ratio and better impact values with similar hardness. Those facts were perhaps of greater importance than the more theoretical basis of the present investigation. The question of which of these three steels should be adopted was often one of economics, and it was common knowledge that silico-manganese steel claimed by far the greatest proportion of the market for automobile springs. Apart from research

work, practical experience had shown that silico-manganese steel was definitely superior to straight carbon steel, and to that extent the conclusions in the paper would probably require modification.

It was rather unfortunate that the silico-manganese steel used in this work should not be representative of silico-manganese steel which was normally used for automobile springs. Silico-manganese steel for oil-hardening contained usually about 0·55 per cent. of carbon, and was only employed in the lower carbon ranges (0·35–0·45 per cent.) for water-hardening. That might account to some extent for the conclusions reached. It had previously been shown that the high-silicon steels tended to scale less but decarburised more readily than steels with low silicon and high manganese and chromium, and his own experience confirmed that previous work. That was contrary to the conclusion reached by the present authors, that chromium-vanadium steel scaled less than silico-manganese steel.

The statement at the top of p. 136 to the effect that the type of gaseous atmosphere played a very small part in the degree of decarburisation up to 1,050° C., and that at a temperature of 1,300° C. little or no decarburisation was found, irrespective of the type of atmosphere, was surprising. It was well known that it was possible to heat in an oxidising atmosphere with comparatively little oxidation, owing to the fact that at high temperatures the decarburised surface was rapidly scaled away. He had not found, however, that the same applied to other types of atmosphere.

In paragraph (1) of the conclusions, reference was made to "type *B* furnace," which had not previously been referred to. That required elucidation. It was surprising to learn that decarburisation actually proceeded during the course of rolling, although this operation only took two or three minutes.

It was important to note that pressure played an important part in this matter of decarburisation, as could readily be demonstrated in a number of ways. Accepting the statement made by the authors, one could only conclude that pressure was playing a part here, and a further expression of opinion on this point would be appreciated.

Finally, the authors, he felt sure, would desire to emphasise that the conclusions reached were based upon the particular method of investigation which they had adopted, and, particularly in regard to the influence of grain-size, &c., would agree that other essential characteristics of the steel apart from the hardness required to be taken into consideration before preference was expressed for one or other type of steel.

Mr. E. MILLINGTON (Derby) congratulated the authors on their paper. The subject was a very important one for a railway

company, and they had been studying it during the last few years. He would first of all like to ask a question or two with regard to the hardness figures given in Fig. 9. They very soon realised in their own work that they were getting hardness differences throughout the section, and they thought it wise to investigate the cause. He ought to say that their steel was of approximately the same composition as the silico-manganese steel to which Dr. Swinden had referred, namely, carbon 0·54, silicon 2·2, and manganese 1·1 per cent. How far the difference in composition affected the question he was not prepared to say. Raw linseed oil was used for quenching, and, in spite of the temperature increase during use, they did not find any pronounced effect on the plates with very wide variations of bath temperature. The quenching temperatures for plates were 890°–900° C., and, on examining the whole of the section, they found by diamond hardness testing at $\frac{3}{16}$-in. intervals that some areas differed from others. By increasing the tempering temperature they eventually arrived at a practically uniform hardness throughout the entire section.

He regarded that as important, because the quenching temperature of 1,050° C. to which the authors had referred (Fig. 10) as giving uniform hardness was, in his own opinion, prohibitive from a practical point of view. There were two aspects which had to be considered. In the first place, heavy scaling and distortion would be introduced. They had found that by using a quenching temperature of 890°–900° C. they were able to reduce distortion to negligible dimensions, with the result that they had now successfully made several thousand springs from the material in question. He could honestly say that in no case could one find a hammer mark on any plate that required fitting, so close had been the final camber after quenching to the original. Fig. A illustrated what he meant, and dealt with silico-manganese steel and carbon steel. The carbon steel was quenched in water, while the silico-manganese steel was quenched in oil, and different temperatures were tried until a condition was reached such that there was more or less uniform hardness throughout the section.

Regarding the statement as to the inferiority of silico-manganese steel as compared with carbon steel, he would like to ask the authors how they proposed to get a carbon steel to give them the physical properties demanded of a spring in an oil-quenched condition ? He could not do it himself, and if the authors had to use water-quenching they would run into difficulties. His own experience regarding the manufacture and behaviour of the two steels was that the silico-manganese steel would be much superior both from the quenching point of view and in regard to its behaviour in service.

Mr. A. E. Frost (Sheffield) said that, following previous publications on the disability of springs by reason of the surface condition of the material, certain spring makers had spared no effort to remove or at least reduce that disability. The present paper was therefore important as indicating that the depth of decarburised material was actually reduced during the usual process of heat treatment. As against that, the statement was made that oxide penetration might be re-introduced during the same treatment. That raised a question of great importance to the spring maker : Was the loss of carbon at the surface or the oxide penetration responsible for the very great lowering of the fatigue strength in spring steels ? It would seem that the spring makers would be seriously handicapped in their efforts to assist in a possible solution of the problem until that question was determined. He hoped that further investigation on the question

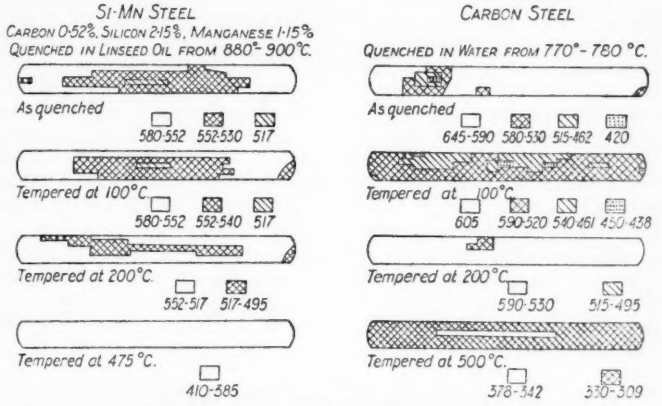

Fig. A.—Brinell Hardness Tests on Spring Plates (Brinell hardness values obtained by conversion from Firth hardometer numbers).

would be made, because the spring makers would not like to think that they had been lured into an enchanted glen and left there indefinitely while that question was settled. They rather feared that, unless they could induce the research workers to carry out those investigations and give them some definite results quickly, that was the state in which they might be left.

The measurement of the depth of decarburisation by means of hardness determinations having been established as the more correct method, it seemed rather unfortunate that that procedure had not been used in the later stages of the work. In Table IV. one was referred back again to the visible method, and he would suggest that if the depth of decarburisation was best measured

by means of hardness determinations this method should be used in all future work.

He would like to ask whether the three heat-treated specimens referred to in Table IV. were machined or unmachined. With regard to the authors' statement in the paragraph headed " Additional Experiments " that " These results show clearly that the machined surfaces on treatment give a greater hardness value than the unmachined," he would suggest that the word " indicate " would be more fitting than the words " show clearly." The statement was made in connection with four results, and only 75 per cent. of them bore out the term " show clearly," the other 25 per cent. contradicting the first three. There was a danger of the term " show clearly " being used where it was not quite justified, because it might easily lose its significance in connection with other results where it would be perfectly justified.

The authors had set out their conclusions Nos. (7) and (8) boldly, and they raised a question as to whether silico-manganese steel had gained its popularity for spring-making largely because the conclusions in other important works had not been so clearly put. The point was an important one. In all the investigations concerned the conclusions were often read without a careful study of the results which led up to them, and, where a desire had been created to apply some of the results of the investigation, unless the conclusions were very well defined there was a danger that a totally wrong interpretation would be applied, differing from that intended by the authors.

Professor Andrew in his introductory remarks used the words " testing on springs," but he believed he meant " testing on spring plates." Spring makers recognised a tremendous difference between the two terms. He thought Professor Andrew would know what he had in mind.

Mr. T. H. Sanders (Leeds) said that the carbon content of the silico-manganese steel at 0·45 per cent. was low, as most standard steels for oil-hardening contained 0·50 to 0·60 per cent. There was presumably a reason for the 0·45 per cent.

It was worth while specially noting that the minimum of billet, bar and spring-plate decarburisation was on sample *Y*, of which the billet was heated in a smoky atmosphere. The old-time technique of Sheffield was based largely on smoky atmospheres, for both re-rolling and spring-bar heat treatment, and there was little doubt that that practice reduced decarburisation, probably partly by surface protection and partly by the reintroduction of carbon into the surfaces from the smoke. He believed the National Physical Laboratory had found that they could replace carbon in decarburised surfaces by painting the bar with graphite before heating it.

The probability was that the second heat treatment for hardening the spring plate actually removed the decarburised surface, which passed away in the scale. That formed a good argument for the double-treatment system—well known in Sheffield many years ago, and on rare occasions now specified—in which the plate was first heated and bent, and then allowed to cool, being reheated for the hardening treatment. By that means it seemed logical that two layers of scale were removed, and the final surface should show very little decarburisation. There was no doubt in the minds of those who knew, of the superiority of the springs made by this process, but commercial considerations of cheap production obviously checked the general employment of the method in question.

He thought the heat treatment as shown in Fig. 9 was not too happy, as the Brinell numbers varied from about 320 to 475 (3·40 to 2·80, 71 to 105 tons) on a plate measuring 3 in. by $\frac{3}{8}$ in. Some comparative figures from two broken plates which he had recently investigated, across the section, and on the surfaces, might be mentioned. A Firth hardometer machine was used:

Section of specimen, 3½ in. by ⅜ in.

Surface 3 marks	3·5, 3·7, 3·5
Top section	2·9, 2·9, 3·0, 3·0, 2·9, 3·0
Middle section	2·9, 2·9, 3·0, 3·0, 2·9, 3·0
Bottom section	2·9, 3·0, 3·0, 2·9, 2·9, 3·0
Surface 3 marks	3·4, 3·5, 3·6

The standard 10-mm. ball for ordinary inspection gave 3·4 and 3·2 on the surfaces. The evidence of decarburisation was clearly shown by the hardometer, as also the effect of that on the reading of the standard ball:

Section of specimen, 4 in. by ½ in.

Surface 6 marks	3·0, 3·0, 3·1, 3·2, 3·1, 3·2
Top section	3·0, 3·0, 3·0, 3·0, 3·0, 3·0
Middle section	3·0, 3·0, 3·0, 3·0, 3·0, 3·0
Bottom section	3·0, 3·0, 3·0, 3·0, 3·0, 3·0
Surface 3 marks	3·3, 3·4, 3·2

The standard 10-mm. ball gave 3·2 and 3·3, respectively, apparently slightly softer but actually practically the same. Evidently there was less decarburisation on that plate, and it must be assumed that the billet of the first example had been substantially more decarburised in the rolling-mill than that of the second, as both had the same spring bar treatment.

The influence of rolling had been rightly emphasised, and it might also be mentioned that the sectional area was a factor in obtaining uniform results with uniform treatment. On that account he had long made it a practice to make a line of demarcation at $\frac{5}{16}$ in. thickness, with a lower carbon for thinner plates than for thicker ones.

The comparisons given for the silico-manganese and the chromium-vanadium steels were of great interest. In practice, the difference between the two qualities was not seriously marked, except for the higher price of chromium-vanadium steel, which militated against its use. The whole matter turned on the treatment of the spring plate, as it was quite possible to produce either quality in a good or bad condition for spring service.

CORRESPONDENCE.

Mr. C. C. HODGSON (Preston) referred to those portions of the paper which dealt with the beneficial effect throughout subsequent operations of a high maximum temperature before rolling. If such results could be shown by experiment to be capable of consistent reproduction with different casts and qualities of steel, they would be of great importance not only in the case of springs but for general constructional steels. It did not appear, however, that the views expressed by the authors were entirely in agreement with their experimental results.

Referring to the maximum temperature of billets *X*, *Y* and *Z* before rolling into plates, the authors stated on p. 134 : " It is remarkable that this high-temperature soaking seems to have an influence on the steel even after treatment subsequent to the original soaking. . . . On oil-hardening and tempering, the

TABLE A.

Billet or Plate Mark.	Temperature of Billet from Table I.	Hardness Number of Plate (Hardened and Tempered) from Fig. 4.
X	1028° C.	370
Z	1260° C.	290
Y	1290° C.	430

samples which were subjected to a high temperature previously invariably gave a harder and more uniform product than those which had not been raised to a high temperature." In support of that statement they cited the hardness curves for heat-treated plates *X*, *Y*, *Z*, Fig. 4.

In Table A were set out the approximate hardness values of the plates ascertained from an inspection of Fig. 4, disregarding surface and decarburisation effects, and, from Table I., the temperature of their respective billets at the time of removal from the reheating furnaces, this temperature presumably being the maximum attained during reheating before rolling. There

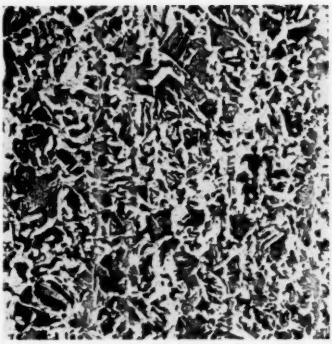

FIG. B.—As Received.

FIG. C.—Heated to 1,300° C.

FIGS. B and C.—Steel *M*1947. × 50.

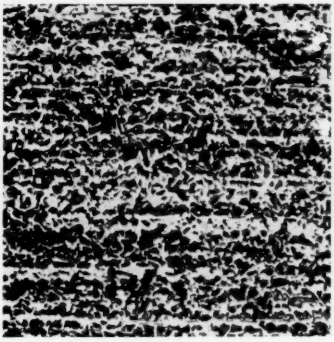

FIG. D.—As Received.

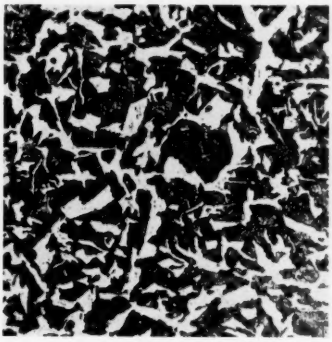

FIG. E.—Heated to 1,300° C.

FIGS. D and E.—Steel *M*1964. × 50.

(See Hodgson's correspondence.)

[*Andrew & Richardson, correspondence.*

[*To face p.* 158.

did not seem to be any relationship between the billet reheating temperature and the plate hardness. A similar objection could be taken to the statement that Fig. 6 presented "a further proof that the initial treatment in a large measure affects the final state of the treated plates," if by this a reference was intended to be inferred to the quotation already made from p. 134 on the effect of initial temperature.

The authors referred on p. 136 to the influence of the amount of ferrite present in the as-rolled plates, pointing out that the greater the amount of this constituent in the as-rolled plates, the lower was the hardness in the oil-hardened and tempered condition. That again did not appear to the writer to be borne out by the evidence in the paper. Whilst it was not possible accurately to estimate the percentage of ferrite present in steels of varying grain-size merely from a visual examination of photomicrographs, it certainly appeared from Figs. 25, 28 and 31 that in the order of decreasing volume of ferrite the order of the plates was *X*, *Z*, *Y*—that was, the higher the reheating temperature the less was the amount of ferrite present. If the order suggested was accepted as correct then the photomicrographs certainly would not confirm the statement as to the effect of the amount of ferrite in the as-rolled plate on the hardness after hardening and tempering, or the reference made by the authors to the results shown in Fig. 8 in confirmation of their contention. In connection with the tensometer tests shown in Fig. 8 no reference was made to the position from which these were taken, and, whilst one naturally assumed that they were all cut from similar positions, it would perhaps not be irrelevant to call attention to the hardness numbers shown in Fig. 9. If the tensile strengths were calculated, it would be seen that the approximate values varied from 68 to 105 tons per sq. in. in different parts of one plate—the "best" plate *Y*—a difference equal to that shown between plates *Y* and *Z* in Fig. 8. The tensometer results, again, showed plate *Z*, with a reheating temperature of 1,260° C., to be inferior to plate *X*, the reheating temperature for which was only 1,028° C.

Some experiments made within the last few months suggested that for straight carbon steel of rather lower carbon content than those used by the authors, neither the amount of ferrite, the size of the ferrite particles, nor the grain-size *produced subsequently to rolling*, had any appreciable effect on the tensile properties of the steel when subsequently hardened and tempered. The following results on two steels would illustrate this. The bars of large grain-size were heated to a temperature of 1,300° C. in a small gas furnace and allowed to cool in the furnace. The micrographs Figs. B to E (Plate VIIIA.) illustrated the structures of the bars in two different conditions. Tensile

test-pieces were machined from the centres of the bars after oil-quenching from 850° C. and tempering at 575° C. The analyses of the steels and the results of tensile tests were as follows :

Mark.	C.%	Si.%	Mn.%	Ni.%	Cr.%
*M*1947 . .	0·33	0·13	0·61	0·28	0·05
*M*1964 . .	0·43	0·23	0·79	0·32	0·06

O.-Q. 850° C.; tempered 575° C.; air-cooled.

Size of bars at time of treatment, 12 × 2½ in. in diam.

	Steel *M*1947.		Steel *M*1964.	
Preliminary treatment . .	None	1300° C.	None	1300° C.
Yield point. Tons per sq. in. .	27·0	26·4	30·3	32·4
Ultimate strength. Tons per sq. in.	41·9	42·4	46·4	47·2
Elongation. % . . .	26	26	25	23·5
Reduction of area. % . .	54·5	52	53	52

Mr. S. A. MAIN (Sheffield) wrote that on some points he could hardly agree with the conclusions which the authors had drawn from their very skilful and thorough research.

The suggestion that a considerable increase in decarburisation resulted during the actual rolling operation and additional to that acquired in the heating preparatory to rolling, would be found specially difficult to accept. It was reasoned from the fact that the measured thickness of the layer on the rolled bars was more than it would have been if the thickness present on the billet just before rolling had been reduced only in the proportion of the surface spread, namely, 3·7 to 1. Such reasoning supposed a uniform thickness of layer on both the billet and the bar, which was not actually the case. The corners of the billet, for example, were more scaled and decarburised, and those corners became, not the corners of the bar, but portions of the flat surfaces. Thus it might well be that the actual ratio of 1 to 2·8 observed was due to the measurement on the billet being taken at a point where the decarburisation was less than at the point corresponding to the position of measurement on the resulting bar.

It was in any case difficult to understand how in the few minutes during which the steel was passing through the rolls it should decarburise to the further extent suggested. The average temperature during rolling was appreciably lower than that of the steel in the furnace, and the mechanical action of the rolling operation in removing the protective action of scale was surely inadequate as an explanation.

With reference to the explanation afforded on p. 134 for the decrease in decarburisation at the higher temperatures, might not a further factor be that the gradient of decarburisation set up by these higher temperatures was steeper. In other words,

some of the surface material which would have remained at lower temperatures as decarburised steel was actually oxidised to the point of scaling off.

It was to be hoped that the assessment as inferior or superior of the different types of steels in conclusions (7) and (8) would not be taken as applying to their value for spring purposes. Clearly the factors which went to make a good spring material were more than those which had been investigated in this research, although these were important. Silico-manganese steel, on a balance of advantages and disadvantages, had proved itself hard to beat, not merely on the score of cost but of performance. With the further knowledge of its characteristics acquired from this research it could be still more so.

The necessity found for a specially high temperature to give fully effective hardening of the silico-manganese steel used in the research could undoubtedly be attributed to its carbon content of 0·45 per cent. While this was representative of much of the steel used of this type, an increase of carbon to about 0·5–0·55 per cent., as employed by several makers, would ensure quite satisfactory hardening at 900° C. in sections of moderate size, as shown by Colbeck and Hanson[1]; for specially large sections, 0·6 per cent. of carbon might be necessary.

Whatever opinions there might be as to the conclusions to be drawn from this research, it had undoubtedly thrown much valuable light on the character and origin of the decarburised layer on spring steel and on other points of practical importance. It should, he considered, be recorded that its initiation was largely due to an excellent body existing in Sheffield and known as the Trades Technical Societies. The normal work of these Societies was the scientific education of the operatives in the various Sheffield trades, and bringing them together for the discussion of their problems. The awakening which took place as a result of the discovery of the decarburised layer and its detrimental effects, and some unwarranted reflections which unfortunately were made as to the technical inefficiency of spring makers, stimulated the Societies to initiate researches on the matter. Under the guidance and active co-operation of Professor Desch and, later, his successor, Professor Andrew, one of the present authors, who undertook the actual scientific examinations necessary, and of the spring manufacturers themselves, the researches were made possible. At the time they were initiated, it was felt that too much attention was being focused on the heating for hardening as the source of decarburisation, and on methods for its correction by attention to that process. The present work had clearly shown the much greater importance of the prior operations in the rolling-mill.

[1] *Journal of the Iron and Steel Institute*, 1924, No. I. p. 377.

AUTHORS' REPLY.

In reply to Dr. Becker, the AUTHORS would point out that the hardness impressions were taken on a Vickers diamond machine with a 10-kg. load, on a section which was machined so as to give a gradient of 10 to 1.

Most of the hardness depth curves could be resolved into three separate gradients, the first from the surface inwards being steep, followed by a curve of lesser slope, ending up with an almost horizontal branch. The slope and length of these slopes varied from one steel to another, but it was noticed that the steepest section corresponded with the depth of decarburisation as observed by micro-examination. It was possible that the micro-measurement of hardness failed on account of the difficulty of differentiating between the excess ferrite and the sorbite when the limiting amount of the former constituent was just reached. It was just possible that gases might play a part in the properties at and near to the surface, and might be responsible for this difference in value between the two methods of measurement.

Dr. Becker referred to the effect of grain-size and gave an explanation of decarburisation on the basis of variation in grain-size. It was generally assumed that grain growth did not occur until diffusion due to heterogeneity ceased. When a state of homogeneity did exist, the carbide particles would be found dispersed throughout the grains in a very finely-divided form, and it was this effect that the authors had in mind when they spoke of carbide expanding like a gas. Thus, the deep hardening characteristics observed with large grain-size might be due to the fine degree of dispersion of the carbide particles rather than to the size of the grains. Uniformity did not appear to be a characteristic of silico-manganese steels, but a high temperature would tend to promote greater homogeneity ; further, it was a fact that the critical changes in these steels was more in the nature of a range. It had been mentioned by other workers that silico-manganese steels contained much gas and swelled perceptibly on first heating.

It was pleasing to note that Dr. Swinden had referred to the impact test, as it seemed quite possible that many springs failed by being suddenly subjected to impact stresses or shock. The authors had recently carried out small-scale tests on what might be regarded as an impact fatigue machine, and the results were most interesting.

With respect to the analysis of the silico-manganese steel, the authors had no control over this, but the differences attributed by contributors to this discussion to the low carbon and manganese contents of the steel employed did tend to show that silico-manganese steels were not quite so fool-proof as they were alleged

to be. The *AE* line in the iron-carbon diagram, for instance, became much steeper as the silicon content was increased, so that small variations in carbon would necessitate large differences in hardening temperatures. Whereas silico-manganese steels might scale less than chromium-vanadium steels, the actual depth of decarburisation was greater, and this was an important feature.

Furnace *B* was referred to in Table II., and details of it were given.

With regard to the effect of pressure during rolling, it was quite possible that the sudden increase and release of pressure as the steel passed through the rolls might upset the conditions of chemical equilibria, and that such reactions as represented by :

$$2FeO + C \rightleftharpoons CO_2 + 2Fe$$

and

$$CO_2 + C \rightleftharpoons 2CO$$

might go in either direction according to the pressure existing.

During rolling operations scale would be removed, resulting in fresh surfaces being exposed to oxidising influences.

The authors would refer Mr. Millington to Fig. 35, which showed very distinctly the non-uniformity of silico-manganese steel. Tempering, in lowering the hardness at all points, naturally lowered the differences in hardness between any points, but the ratios of these differences in the quenched and the tempered conditions was approximately the same. For making an industrial spring of a plain carbon steel, water-quenching would naturally be necessary.

In reply to Mr. Frost, the authors would say that undoubtedly oxide penetration was more detrimental than mere surface decarburisation, since it initiated intercrystalline weakness.

The section referred to by Mr. Frost was unmachined. With respect to the further result referred to, the two hardness values were the same ; it was probably just a mere chance that the two surfaces were identical.

Mr. Saunders' remarks were interesting, and the authors agreed largely with what he had said.

With reference to Mr. Hodgson's criticism, it should be noted that example *Z* had only remained at the high temperature of 1,260° C. for a very short time, and therefore was not to be compared with examples *X* and *Y*. The statements referred to by Mr. Hodgson were based largely on laboratory tests and had been confirmed many times. The amount of reduction per pass during rolling might quite readily be a contributory cause of particular hardness values in carbon steels, and it was for this reason that it was a pity that silico-manganese steel was not used.

The authors had clearly shown that the effect of the quenching temperature on plain carbon steels was negligible, and Mr. Hodgson's results were therefore in agreement with their own.

Most of the points raised by Mr. Main had already been dealt with. They wished to point out to Mr. Main, and to other critics, that the investigation under discussion referred entirely to the scaling, decarburisation, hardness features and microstructures of spring steels, and the actual mechanical properties of springs had not even been touched upon. Nevertheless, the authors were strongly of the opinion that the surface and internal structures of any steels were fully worthy of detailed consideration.

THE RESISTANCE OF SPRING STEELS TO REPEATED IMPACT STRESSES.*

By G. A. HANKINS, D.Sc., and H. R. MILLS, B.Sc.
(National Physical Laboratory.)

Summary.

The investigation was carried out to determine whether the irregular decarburised surface which is present on a normal heat-treated spring steel plate affects the resistance to repeated impact stresses.

Single blow and repeated blow impact tests were carried out on three heat-treated spring steels, in the machined and polished and in the as-rolled and heat-treated conditions, using unnotched specimens. Tests were also made on a surface carburised plate and on a steel which had been machined and then heat-treated in such a manner as to minimise surface decarburisation; both these materials possessed high endurance fatigue limits for cyclic stresses. The repeated impact tests were made with a wide range of impact energy, varying from an impact which would break a test piece in a few hundred blows to one which a test piece would resist for over one million blows.

For nearly all the materials the results suggest that a repeated impact endurance limit is revealed by tests on a one-million impact endurance basis. In general, the irregular decarburised surface on a spring plate produces a low repeated impact endurance limit (10^6 impacts) in the same manner as it produces a low endurance fatigue limit; the defective surface appears to have no adverse effect, however, on the resistance to a large impact of magnitude approaching the full single blow impact strength of the plate.

Introduction.

Previous investigations[1,2,3] made at the National Physical Laboratory have shown that the fatigue resistance of spring steel plates in the normal as-rolled and heat-treated condition is much less than the intrinsic fatigue resistance developed by the materials when disturbing surface conditions are eliminated by machining and polishing. It has also been shown that the surface decarburisation which occurs during the manufacture and heat treatment of the steel is one of the main causes of the low fatigue resistance of the unmachined plates. In these previous investigations the fatigue tests employed in the work have consisted of repetitions of cyclic stress without impact—either reversed bending stresses on cylindrical specimens (rotating beam tests) or repeated bending tests on plates. The latter form of test

*Communication from the Engineering Department, National Physical Laboratory, received January 16, 1935.

applies stresses which are similar to the primary bending stresses set up in the plates of a laminated spring under service conditions; but many laminated springs in service are not only subjected to cyclical variations of stress but also to impact forces. From existing knowledge of the behaviour of steels under repeated impact,[4,5] it might be surmised that surface conditions which lowered the fatigue limit would also be detrimental under repeated impact conditions, provided the number of impacts before failure were high. Against this, however, it could be suggested, not unreasonably, that a surface layer of soft decarburised material might be beneficial under impact conditions. No previous investigation which gave definite information on these matters appeared to have been carried out, both Stanton's and McAdam's tests having been made on machined notched specimens, and accordingly the present series of tests were made to examine the effect of surface conditions on the repeated impact resistance of certain available spring steels; single blow impact tests on the materials were also included. The work described has been carried out in the Engineering Department of the National Physical Laboratory, as part of the investigation on the effect of surface conditions on the fatigue resistance of steels supervised by the Executive Committee of the Laboratory.

Materials and Heat Treatment.

The materials used in the tests were a chromium-vanadium spring steel and two silico-manganese spring steels. The chemical analyses of the steels are given in Table I. below. Two of these steels, Reference Nos. S5 and S6, were high quality standard spring steels, whilst the remaining silico-manganese steel was a commercial spring steel in use in this country. The steels were originally in the form of 3 in. by $\frac{3}{8}$ in. rolled spring plate. All three steels have been used in previous investigations on the effect of surface conditions on the fatigue strengths.

Table I.—*Chemical Analyses.*

Steel.	Reference Mark.	C. Per cent.	Si. Per cent.	S. Per cent.	P. Per cent.	Mn. Per cent.	Ni. Per cent.	Cr. Per cent.	V. Per cent.
Chromium-vanadium steel . . .	S5	0·55	0·29	Trace	0·01	0·68	0·10	1·16	0·27
Silico-manganese steel, commercial . .	EGI	0·53	2·06	0·03	0·04	0·81	..	..	..
Silico-manganese steel	S6	0·54	1·95	0·02	0·02	0·94	..	..	..

Five series of tests were carried out on these steels; the heat treatments to which the steels were subjected are given in detail below.

A. Chromium-Vanadium Steel, S5.—The heat treatment was carried out at the laboratory; each plate (about 18 in. long) was held in a gas muffle at 850° C. for about 1 hr., quenched in oil, and then tempered at 600° C. The long exposure in the furnace was used in order to allow a certain amount of surface decarburisation to occur during the heat treatment.

B. Silico-Manganese Steel, EGI.—Plates about 18 in. long were supplied to the laboratory in the heat-treated condition. No details of heat treatment were available but it was stated that a normal commercial heat treatment for this type of steel had been used.

C. Silico-Manganese Steel, S6.—The heat treatment was carried out at the laboratory; each plate (about 18 in. long) was held in a gas muffle at 950° C. for about 1 hr., quenched in oil, and subsequently tempered at 500° C. As in the case of the chromium-vanadium steel, the long exposure in the furnace was used in order to allow a certain amount of surface decarburisation to occur.

D. Silico-Manganese Steel, S6, Graphite Heat Treatment.—The surfaces of the original plates were removed by machining away about $\frac{1}{16}$-in. from each face before heat treatment. The heat treatment temperatures were the same as those in series *C*, but the heating prior to quenching was carried out with the plates covered in graphite powder.*

E. Chromium-Vanadium Steel, S5, Carburising Heat Treatment.—This particular heat treatment was an experimental treatment which had been used in studying the effect of slight surface carburising on the fatigue strength of spring steel plates.

TABLE II.—*Hardness Tests.*

Material.	Treatment.	Average Diamond Pyramid Hardness Number HD/10		
		Interior.	Surface.	Difference.
Chromium-vanadium steel, S5	O.-Q.850° C., T.600° C.	406	359	47
Silico-manganese steel, EGI.	Commercial	457	288	169
Silico-manganese steel, S6	O.-Q.950° C., T.500° C.	469	226	243
Silico-manganese steel, S6	Graphite treatment	473	476	..
Chromium-vanadium steel, S5	Carburising treatment	694	750	..

* For further details of this treatment see Reference No. 3.

It consisted of holding the as-rolled steel plates in a sodium cyanide bath at 850° C. for 2 hr. and then quenching direct in oil ; no tempering treatment was applied.

Hardness tests were made on the specimens prepared for the impact tests, and the results obtained are summarised in Table II.

It will be noted that the surface softening of the chromium-vanadium steel was considerably less than that of the two silico-manganese steels when no special treatment was used. There was no appreciable difference in hardness between the interior and the surface of the graphite-treated steel ; slight surface hardening was present in the carburised steel.

Test Methods—Repeated and Single Blow Impact.

Preliminary tests indicated that unnotched test pieces, 10 mm. × 5 mm. in section and 60 mm. long, would be satisfactory for both single blow and repeated impact tests, and test-pieces of these dimensions, as shown in Fig. 1, were employed for all the tests. These small test-pieces could be conveniently prepared from the enlarged ends of heat-treated plates which had been used for bending fatigue tests in other investigations.

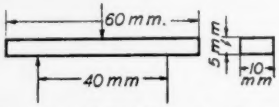

Fig. 1.—Dimensions of Test-Pieces for Repeated Impact Tests.

A Stanton repeated impact testing machine was used for the repeated blow tests after certain modifications had been made.* The machine was provided with new anvils, 40 mm. apart, and clamps were designed to keep the test-piece in contact with the anvils without imposing any bending moment upon it or interfering with its free vibration. The mechanism for turning the specimen over between blows was removed, so that the same face of the specimen, the unmachined face in the case of the as-rolled test-pieces, was in tension for every blow. A knife-edge of large radius was attached to the striking face of the hammer, and weights which could be rigidly attached to the hammer were employed in those tests which required a large energy of impact. Fig. 2 shows the method of gripping the specimen for test. The machine was bolted to a heavy concrete floor during the whole of the tests.

The machine was run at a speed of 100 blows per min. ; the energy of blow was varied over a large range so that specimens

* T. E. Stanton, "Repeated Impact Testing Machine at the National Physical Laboratory," *Engineering*, 1906, vol. 82, July 13, p. 33, gives a full description of the original machine.

were broken after a number of blows varying from 45 to over 1,000,000. Specimens which endured 1,000,000 blows without fracture were removed from the machine.

Variations in the energy of blow were generally made by altering the height of drop and not the weight of the hammer,

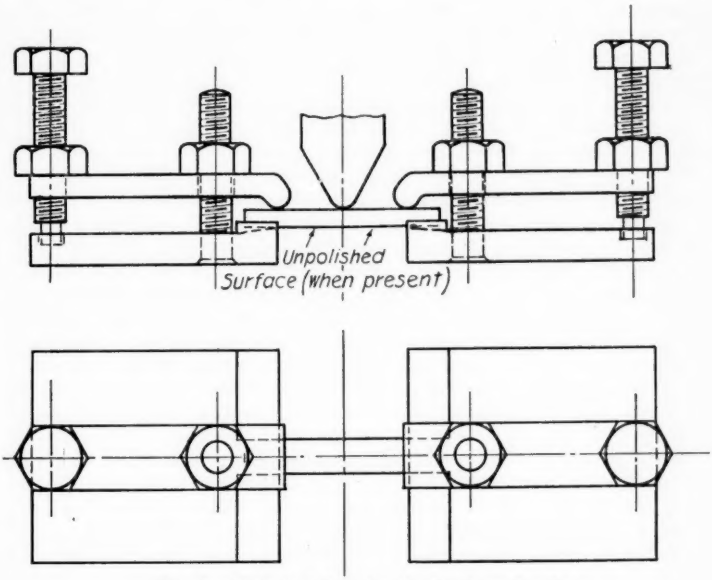

FIG. 2.—Method of Gripping the Specimen for Test.

but in a few tests at high impact energies, additional weights were added to the hammer.

For the single blow impact tests a machine of the Charpy floating anvil type (maximum energy of blow 192 ft.-lb. and striking velocity 17 ft. per sec.) was used.

RESULTS OF TESTS.

Each test series consisted of single blow and repeated impact tests on specimens containing a test surface representative of the untouched surface of the plates after heat treatment, together with similar comparative tests on completely machined and polished specimens. The specimens containing representative surfaces were obtained by grinding from one side only of the

original plate, and these specimens were tested with the unmachined surfaces as the tension faces during the actual tests. In the preparation of the completely machined specimens equal amounts were ground from both faces of the original $\frac{3}{8}$-in. plates so that any defective surface layer—or the carburised surface layer in series *E*—was completely removed. All specimens were accurately ground to the test thickness of 5 mm. so that the presence of the unmachined tension surface was the only difference between specimens which are referred to as polished or as unpolished specimens in each test series. The normal type of failure in a repeated impact test was by means of a fatigue crack starting on the tension side near the position of maximum stress. In the single blow tests failure usually occurred in the same position as in the repeated impact tests, but the characteristic fatigue marking was absent of course. It should also be mentioned that repeated impact test fractures in which failure occurred after a small number of impacts were not appreciably different in appearance from the single blow fractures ; in all such cases appreciable permanent bending of the specimen was also present.

The results of the tests are shown plotted to logarithmic scales in Fig. 3. There is a certain amount of scatter of results, but in each case a mean straight line can be drawn through the points to include the single blow test, with the exception of the results from the tests on carburised steel in the unpolished condition. With one exception, all the lines show some indication of a change in slope in the region of 200,000 to 400,000 impacts, and although tests to a much higher endurance would be necessary for any definite positive conclusion, the endurance tests on a basis of one million impacts may possibly be sufficient for approximate repeated impact endurance limits to have been reached in eight out of the nine sets of tests. In any case, however, the tests on the one million impacts basis appear to give sufficiently definite information for a comparison of the various materials and the effects of the different surfaces to be made. These comparative figures are collected in Table III. below, which also includes the results of repeated bending fatigue tests (cyclic stress, mean stress equal to one-half the range of stress) carried out on some of the materials.

Ratios of the square roots of limiting energies are also given in Table III. in order to afford a more correct comparison of the repeated impact tests with cyclic fatigue tests. The work per unit volume which is stored up in an elastic material under bending impact stresses is proportional to f^2/E, where f is the maximum stress and E is Young's modulus of elasticity. In the present tests the dimensions of the impact test piece were the same throughout and so the maximum stress corresponding to a particular limiting energy of blow is proportional to the

TABLE III.—*Summary of Results of Impact Tests.*

Material.	Treatment.	Single Blow Impact Tests. Energy to Fracture. Ft.-lb.		Repeated Impact Tests. Limiting Energy of Blow. Ft.-lb. for 10^6 Impacts.				Fatigue Tests (Repeated Bending). Limiting Range of Stress. Tons per sq. in.		
		Polished.	Un-Polished.	Polished. A	Un-Polished. B	Ratio. B/A	Ratio. $\sqrt{B}/\sqrt{A}$	Polished. C	Un-Polished. D	Ratio. D/C
Chromium-vanadium steel, (S5).	Normal heat-treatment. Test Series *A*.	82	84	0·68	0·27	0·40	0·64	56	33 Approx.	0·6 Approx.
Silico-manganese steel, (EGI).	Commercial heat-treatment. Test Series *B*.	55	71	0·70 Approx.	0·30	0·43 Approx.	0·66 Approx.	46	18	0·4
Silico-manganese steel, (S6).	Normal heat-treatment. Test Series *C*.	62	69	1·0	0·23	0·23	0·48	55	30 Approx.	0·55 Approx.
Silico-manganese steel, (S6).	Graphite heat-treatment (after machining). Test Series *D*.	62	61	1·0	0·55	0·55	0·74	55	50	0·9
Chromium-vanadium steel, (S5).	Carburising heat-treatment. Test Series *E*.	65	7	0·9	0·50	0·55	0·75	..	60	..

square root of that limiting energy. Accordingly ratios given in the sixth column of figures, and not those in the fifth column, should really be compared with the ratios given in the final column of Table III.

Considering the results, it will be noted that in test series *A* there is no appreciable difference between the single blow impact values for the polished and unpolished surfaces, but the impact endurance limit for the unpolished material is less than one-half that of the polished material. In the single blow tests in series *B* the unpolished surface gives a slightly higher result than the polished surface, but again the impact endurance limit of the unpolished material is much less than that of the polished material. In test series *C* there is no indication of a change of slope in the line of the plotted results of the unpolished material (see Fig. 3), but it is clear that the repeated impact resistance of this unpolished material is much less than that of the polished material. In these three series (*A*, *B* and *C*) the impact endurance limits agree qualitatively with plane bending fatigue endurance limits in that the polished surfaces are much superior to the unpolished surfaces.

In test series *D* it was considered unnecessary to carry out separate tests on polished specimens, since such tests would be practically the same as the tests on polished specimens of series *C*. The impact endurance limit for the " graphite " surfaces is higher than that of any of the unpolished surfaces of series *A*, *B* and *C*, but not much more than one-half that of some of the polished surfaces.

The values obtained on the polished specimens of series *E* are results on a spring steel which had not been tempered. Considered from this point of view the results are largely what would be expected ; the single blow values are lower than those of series *A*, but the impact endurance limit is higher than in that series. The single blow impact result on the unpolished specimens of series *E* is very low, but the impact endurance limit is higher than that obtained on the unpolished surfaces of series *A*, *B* and *C*, and thus agrees with the results of cyclic fatigue tests.

Considering the results in general, the repeated impact endurance limits correspond to the results of endurance cyclic fatigue tests. Series *A*, *B* and *C* show quite clearly that the irregular decarburised surface which is present on a normal unmachined heat-treated spring plate is undesirable when high resistance to a large number of impacts is required. The results confirm the original surmise that surface conditions which lower the endurance fatigue limit also lower the repeated impact endurance limit.

For a very small number of blows, the repeated impact tests fit in with the results of single blow tests, and in these cases the

Cr-V Steel, S.S. Ordinary heat-treatment

Si-Mn Steel, E61, Si-Mn Steel, 56 Cr-V Steel, 55
Commercial Ordinary & Graphite Carburising
heat-treatment heat-treatments heat-treatment

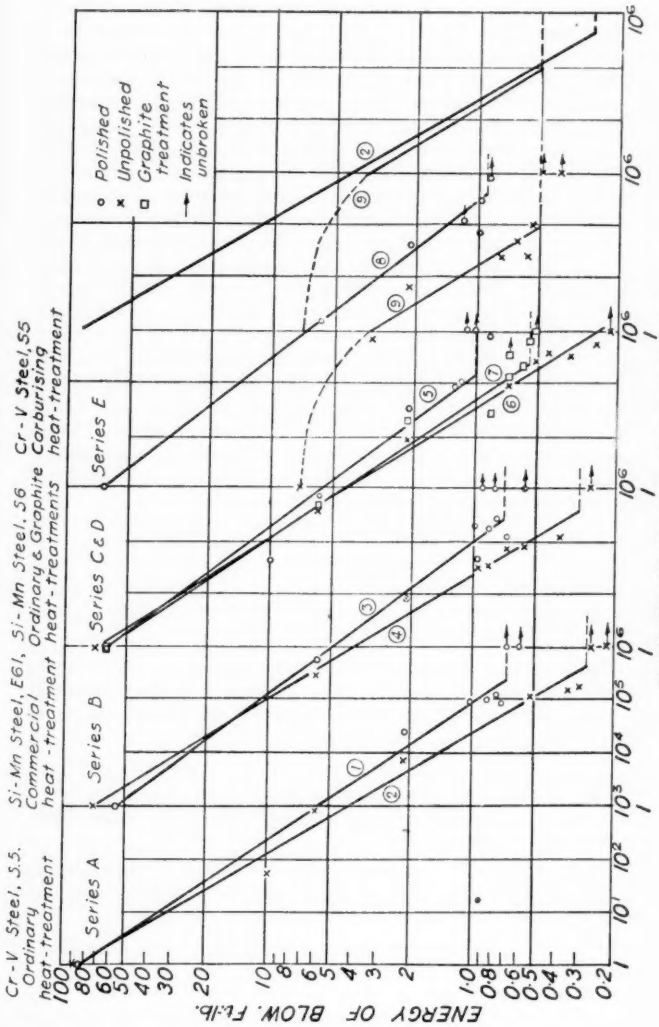

FIG. 3.—Repeated Impact Tests.

soft decarburised surface layer may not be objectionable and might even be of value. With a uniform spring steel free from surface decarburisation there is little doubt that the single blow impact value would be less when surface irregularities were present than when they were absent, since the irregularities would act as small notches. But the actual results in series *A*, *B* and *C* show that the single blow values for the unpolished surfaces are the same as or higher than those for the polished surfaces, and this must be attributed to the soft surface layers reducing the effects of stress concentrations set up by the irregularities of shape. It appears, however, from the experimental results (see Fig. 3) that this effect only holds good for a very small number of impacts and has no practical significance for a normal laminated spring. The tests on the carburised material of series *E* represent an extreme case in which the single blow impact value is very low and the repeated impact endurance limit (and also the cyclic fatigue limit) is high. Comparison shows that the repeated impact curve of results for this carburised material is below the curves for the other unpolished materials until a value of over 1,000 impacts is reached (see comparison of curves 2 and 9, Fig. 3). It appears that this untempered, unpolished, carburised steel would be unsuitable for laminated springs subjected to impact, despite its high endurance fatigue limit.

Conclusions.

The following conclusions are drawn from the results of the tests :

(1) The irregular decarburised surface which is present on a normal heat-treated spring plate produces a low repeated impact endurance limit (10^6 impacts) in the same manner as it produces a low endurance fatigue limit.

(2) The irregular decarburised surface on a spring steel does not appear to have any adverse effect on the resistance to a large impact of magnitude approaching the full single blow impact strength of the plate.

(3) The "graphite" heat treatment, which has been shown to give a high endurance fatigue limit for spring steels, may also be useful for improved resistance to repeated impact.

(4) In general, the results show that Stanton and Bairstow's conclusions for notched test pieces apply to both machined and unmachined spring steels in that the behaviour under a very small number of impacts is indicated by the result of a single blow test, but that repeated impact endurance limits correspond to the results of cyclic fatigue endurance tests.

ACKNOWLEDGMENTS.

The work described has been carried out as an item of a research financed by the Department of Scientific and Industrial Research and supervised by the Executive Committee of the National Physical Laboratory; the authors desire to record their appreciation of the opportunities afforded for carrying out the work and for permission to publish the results.

The authors also desire to acknowledge the help and encouragement given by Dr. H. J. Gough, F.R.S. (Superintendent of the Engineering Department, National Physical Laboratory), during the progress of the work.

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CORRESPONDENCE.

Mr. A. E. Frost (Sheffield) asked if, in connection with the statement at the top of p. 166, the authors would define the type of service conditions they had in mind which produced the impact forces referred to ; and was the statement founded on reasonable deduction or did it follow the result of some prior investigation ?

With regard to the description of the testing machine on p. 168, where mention was made that clamps were designed to prevent any interference with free vibration of the test specimen, surely that indicated a deflection ? Could the amount of *deflection* when the machine was running at a speed of 100 blows per min., say, at 1·0 ft.-lb., be given ?

If no observations were taken of this measurement could such an observation be taken and the corresponding maximum stress due to *bending* be given when the machine was running at its normal speed of 100 blows per min. ?

The thought behind that question was that a very small movement, say, 0·01 in., would possibly result in a stress sufficiently high to produce failure by repetition of bending.

Was it possible to give particulars as to where the fractures occurred ? (A distance from the centre line covering the bulk of the fractures would suffice.) The writer's suggestion was that the form of test specimen used was masking a disability probably as great as the surface condition of the material.

The paper was interesting, but if further investigations were undertaken could the conditions be such as would provide possibilities of useful application ?

As an example : Machine grinding of the material could be commercially applied in certain cases, but polishing was not applicable. The information desired by the spring manufacturer, therefore, became : " What increase in fatigue strength is likely to be obtained by grinding the surface a minimum of $\frac{1}{32}$ in. ? "

Recent investigations, other than the present work, pointed very strongly in the direction that the problem of the greatly reduced fatigue resistance of springs compared with the established intrinsic fatigue resistance of the material was still a long way from solution, and the writer suggested that the most useful investigation towards further progress was the endurance testing of actual springs, with particular reference to the stresses imposed under service conditions, on which subject much information was now available.

If the writer understood the footnote on p. 165 correctly, the authors were to be congratulated on the speed with which the many results had been obtained, and although the writer had failed to discover much practical usefulness in the paper, the

replies to some of the questions now raised might considerably alter that opinion.

Mr. H. SUTTON (Farnborough) wrote that the paper by Hankins and Mills adduced further valuable data on the low mechanical properties of the surface layers on heat-treated spring steels, and indicated the desirability of removing the affected layers or avoiding the deterioration.

The authors had afforded useful guidance in the use of both these measures. The cause of the low properties interested the writer personally, and the point arose as to whether decarburisation *per se* was the root cause. It appeared to the writer possible that penetration of oxygen under conditions conducive to decarburisation might be the more important factor. Recent work at Farnborough had shown that the fatigue properties of heat-treated and aged duralumin were improved by machining off the surface layers after heat treatment, and in that case decarburisation could not be the cause. Penetration of oxygen was known to occur and had been observed microscopically in heat-treated steels by several investigators. Further, in their work on spring steel wires at Farnborough the writer and his co-workers had found evidence of further improvement in fatigue properties by the removal of surface layers after the decarburised material had been removed completely.

While, therefore, it was essential that the effects observed by the authors, and their practical importance, should be fully recognised, it seemed very important that an open mind should be maintained on the matter of the mechanism, until more concrete evidence had been established and all possible causes more fully investigated.

Mr. S. A. MAIN (Sheffield) wrote that the present paper had supplied a much needed requirement in establishing a bridge between the impact strength of spring steels and their resistance to fatigue. Those engaged in the manufacture of automobile springs, or otherwise concerned practically with their performance, had little doubt that resistance to fatigue was not the sole consideration, but that actual shocks had an influence on their life, and in some cases an important one. Although in some respects the facts provided by this research might be perplexing, in others they were of undoubted assistance towards the solution of this problem.

It was of course well known that a spring of which the material was heat-treated to a high hardness so as to give exceptional resistance to fatigue, was quite unsafe to use on account of its low resistance to impact, and this was well confirmed by the authors in the tests carried out in series *E*. Incidentally, a feature

of modern research on fatigue had been to establish the importance in some cases of plastic accommodation of the material, especially under conditions where there was a high mean stress, as in the present research. Such accommodation was more likely to occur in mild and ductile steels, but since in the present spring steels the highest fatigue value was obtained at the highest hardness, no advantage as regards fatigue could be derived in their case from encouraging a measure of ductility in the steel.

The difficulty in making use of the present results lay in assessing just how much value was to be accorded to the ability to resist impact and how much to the resistance to fatigue. In different vehicles and different conditions of service the relative importance would undoubtedly vary. Taking the experimental data in the present paper, it might be said that the normal condition of the chromium-vanadium steel represented by line 2 in Fig. 3 was undoubtedly a more satisfactory one than that represented by line 9, where the steel was in a particularly hard condition.

Under blows of anything between 0·5 and 4·0 ft.-lb. the performance of the two materials was to all intents and purposes the same ; each had a life of from 1,000 to 100,000 impacts, according to the severity of the blow. Under lighter blows the harder steel was superior ; it was only with a succession of heavy blows of more than 4 ft.-lb. that the harder steel showed the same inferiority as it did in practice. It would therefore appear that practical conditions were more nearly equivalent to the succession of heavy blows, and that the best steel for springs was to be determined, not by fatigue tests of the usual kind, but by impact fatigue tests of this rather severe order.

If this was so, and referring to the other lines of Fig. 3, the practical advantages or disadvantages of the particular treatments considered would appear to be of a very small order. Decarburisation in particular was also, for the same reason, probably not so detrimental in practice as was indicated by simple fatigue tests.

AUTHORS' REPLY.

The AUTHORS wrote in reply to Mr. Frost that whether or not a particular type of stress application caused impact was bound up with the rate at which stress waves were propagated through the metal of the spring and also reflected, and they were not prepared to say much on this matter at present ; but they thought it would be agreed that under normal running conditions vertical impact was greater with a heavy laminated spring than with a light spring, owing to inertia effects. Thus, repeated impact was likely to be more important in a railway

spring than in a light car spring. Again, excessive friction in a spring gave rise to impact forces. Further, impact obviously occurred when a laminated spring came against a stop limiting the vertical deflection, and also arose from longitudinal and transverse forces on the spring. The deflection of the test-pieces had not been measured; it would not be an easy observation to make. In regard to equivalent maximum bending stresses in the impact tests, it might be suggested that some idea could be obtained by working out the stresses from the energy of the blow and the usual formula, but unfortunately in any test of this sort a considerable amount of energy was absorbed by the machine parts and foundations, and results thus obtained would therefore be much higher than the correct values. Accordingly, the authors considered that the method by which the ratios of the square roots of the limiting energies in impact tests were compared with the ratios of the fatigue results, as in Table III. of the paper, was all that was justified in comparing the stresses in the impact tests with the stresses in the fatigue tests. All the failures in the impact tests occurred at or very close to the centre of the test-piece, at the position of maximum stress, and although it would have been preferable to use larger test-pieces with a greater surface subjected to the maximum stress (involving, of course, a much larger testing machine) they could not agree that the form of the test specimen affected the major conclusions arising from the work in any way.

They were pleased to hear from Mr. Frost that the machine grinding of springs could be applied commercially in certain cases; it seemed probable that the removal of a surface layer of $\frac{1}{32}$ in. would remove all the defective surface layer, and then the fatigue resistance of the steel was dependent on the grinding marks; simple routine fatigue tests on ground specimens should give direct information on this matter.

The authors thanked Mr. Sutton and Mr. Main for their appreciative remarks on the paper. Their views on the question of the possible penetration of oxygen were given in the *Journal of the Iron and Steel Institute* (1931, No. II. pp. 458–460); in brief, they agreed that oxygen penetration could and did occur, but at present the evidence on the matter suggested that the oxygen penetration in spring steel did not extend beyond the decarburised layer. That, of course, did not explain Mr. Sutton's results on steel wires, nor would the authors attempt to explain these particular results, although, of course, they accepted them as being correct.

They agreed with Mr. Main that it was difficult to assess the relative importance to be attached to fatigue and impact resistance for particular service conditions; they regretted that they could give very little real help on this matter, but in general they were

inclined to attach considerably more importance to fatigue resistance than to impact. Possibly it might help Mr. Main to know that in the present tests, visual observation suggested that in the region of 1,000 impacts the type of fracture began to change from the single-blow impact type to the typical fatigue type. This did not pretend to be an exact statement, but since nearly all spring fractures appeared, by visual examination, to be fatigue fractures, it rather suggested that failures in service were not due to a comparatively small number of heavy impacts. Further, in an average spring steel, it appeared from the present tests that an impact which could fracture the steel by 1,000 blows gave much more marked permanent bending than occurred in a normal plate in service.

AN EFFECT OF OXYGEN AND SULPHUR ON IRON IN SCALING.[1]

By J. H. WHITELEY, F.I.C. (Consett).

Abstract.

A network structure which forms at the boundaries of either α or γ surface grains when steel is scaled is described and studied. It is revealed by the usual etching reagents, including cupric, and its intensity depends, in part, upon the temperature and length of heating. The structure does not penetrate far, and is primarily due to the presence of oxygen in the scale exceeding the ferrous-oxide phase requirement. When steel is welded by wash heating, the structure is usually to be found at the weld junction. It disappears, apparently by diffusion, when heated in the absence of oxygen at the higher temperatures in both the α and γ ranges, the rate increasing with the temperature. In purer materials, such as electrolytic iron, the structure is either extremely weak or fails to appear. This variation is traced to the influence of sulphur, which causes intensification, but, along with it, other elements may also have some effect. The action of sulphur on scale intrusion at the austenite grain boundaries is also discussed. Finally, the characteristics of the structure are compared with those of the ferrite bands in the banded structure of rolled steels, and the similarity is sufficiently marked to suggest that both are due to the same cause, namely, a heterogeneous distribution of oxygen and sulphur in the metal.

Introduction.

In 1921 a paper was published by Stead[2] in which was described a structure he had found at the surface of a steel casing from an ironworks stove. This casing had been in use for many years in an oxidising atmosphere and was heavily scaled, but the temperature at which it had been normally maintained was not stated. When cross-sections of scale and steel were treated with a cupric reagent, a white network appeared at the borders of the α-grains just beneath the scale. An excellent photograph of this structure was given and it was stated that, after long etching and repolishing, the network stood up in slight relief. Some time ago a similar effect was observed by the author when examining a specimen of Armco iron which had been heated in air for about 2 hr. at 960° C The section had been well etched with picric acid, and, starting at the surface, tapering veins, in strong contrast, penetrated a short distance into the steel, as shown by cupric etching in Fig. 12 (Plate X.). Unlike Stead's example these network

[1] Received January 8, 1935.

[2] *Journal of the Iron and Steel Institute*, 1921, No. I. p. 271.

ridges did not occur at the α-grain boundaries, but they seemed to be quite as prominent. It was certain that the structure was produced during scaling, and a closer study of its formation and characteristics was undertaken. As the work proceeded it became evident that oxygen in some form was passing into the metal from the scale. The subject, therefore, makes one of several difficult problems connected with the presence of oxygen in iron, and while there is scope for much further inquiry it is hoped that the present contribution will not be without value.

During the investigation many iron and steel samples differing widely in composition have been used. In Table I. the analyses are given of those to which reference is made.

TABLE I.—*Chemical Analyses of Samples.*

Sample No.	Material.	C.C. Per cent.	Si. Per cent.	S. Per cent.	P. Per cent.	Mn. Per cent.
1	Electrolytic sheet .	Trace	Nil	0·006	0·005	Trace
2	Armco iron . .	0·02	Trace	0·032	0·005	0·038
3	Basic steel plate .	0·04	0·005	0·021	0·006	0·10
4	Acid steel bar . .	0·73	0·14	0·039	0·033	0·72

Three etching reagents have been employed, namely :

(1) A saturated solution of picric acid in alcohol.
(2) A 5 per cent. solution of nitric acid in alcohol.
(3) Le Chatelier and Dupuy's.[1]

In the preparation of the surfaces for examination, the procedure was to detach most of the scale by abrasion on a fairly coarse emery paper, and to continue on the finer emery papers, removing as little metal as possible. The polished specimen was next etched for a few minutes with picric acid and then buffed again very lightly on the wet cloth. This served to flatten the network ridges sufficiently to make them sharply defined. A second etching for about 10 sec. in nitric acid was useful, as it intensified the contrast and also rendered the structure more apparent in cases where diffusion had occurred. For visual work these two reagents gave excellent results, but for the purpose of illustration the cupric reagent was more suitable, owing to the difficulty in obtaining a satisfactory representation of structures standing up in strong relief. It gave comparable effects when applied either to the polished surface or after the picric etch. To illustrate this Figs. 1 and 2 (Plate IX.) are given; they show the same area after treatment with the cupric and picric reagents, respectively.

[1] *Comptes Rendus*, 1917, vol. 165.

The general method of scaling was to heat the specimens in a horizontal electric resistance furnace open at both ends. Except when stated otherwise, they were fastened on a holder of thin nichrome wire and inserted directly against a thermocouple placed near the centre of the furnace.

Section I.

For the study of the structure at the outset sample No. 2 was chiefly used. Small pieces were heated, for varying periods, at temperatures between 920° C. and 1,050° C. and allowed to cool in air. It was found that the network was formed in all. Two minutes at 930° C. gave the distinct but rather weak structure shown in Fig. 3. As the length of the heating was increased, and as the temperature was raised, the network became more intense; that is, less etching was required to render it visible and full etching brought it out in greater relief. Figs. 1 and 2 show the strong effect obtained after heating a specimen for 1 hr. at 1,050° C.; Fig. 4 illustrates a typical intermediate result. Even after heating for several hours at the higher temperatures the structure still persisted as a network, the area of the meshes remaining almost unaltered below 1,000° C. There, however, after heating for about 1 hr., another feature became apparent in the shape of a thin layer, next to the scale, of a ferritic substance which, like the network, resisted the attack of the reagents. This material appeared to consist of the interstitial walls that had formed between the scale and metal. It thickened when specimens which had been scaled at 970° C. were heated for another hour at 930°C., especially if this was done in a closed tube. In Fig. 7 (Plate X.), the dark scale, the white layer as a fringe, and the underlying network, are all shown. Many observations indicated that as scaling was accelerated the layer diminished in thickness, but, beyond noting its presence in other samples very low in carbon, little further attention was given to it.

The depth to which the network structure penetrated was repeatedly examined in sections cut normal to the scaled surface and was not found to exceed $\frac{1}{300}$ in., as indicated in Fig. 12. Numerous attempts were made to increase this distance, by heating specimens for long periods at different temperatures, but without success. In some places a surface grain would be enveloped; at others, veins which had started to travel inwards would quickly taper and vanish.

In these initial experiments the pieces were quickly heated to the selected temperature and air-cooled. The next step, therefore, was to examine the effects produced under varying speeds of heating and cooling. Quite a number of tests were made, and it may be stated, without entering into detail, that a slow

rate of heating did not affect either the formation or character of the structure, nor did quenching in water; but, when slow cooling was tried, a change was at once observed. The network became less sharply defined in a manner which suggested that diffusion was taking place.

To study this feature properly it was clearly necessary that the structure should be obtained under a standard condition, so as to get approximately the same intensity in each specimen. This was done by heating the pieces separately for 1 hr. at 970° C. in a silica tube open at one end, 10 in. long and 15 c.c. in capacity. The structure thus produced was similar to that seen in Fig. 4. It was also essential that further scaling should be avoided. For this purpose two methods of procedure were adopted. One was to close the tube when the specimen had been heated for an hour, and, after allowing 15 min. for most of the enclosed oxygen to be absorbed, to raise or lower the temperature quickly to the point at which the piece was to be held. The other method was as follows: Some drillings of electrolytic iron were placed at the far end of the tube and the scaled specimen was placed at the open end. The tube was then closed and inserted to about one-half its length in the furnace at the required temperature. After the drillings had been heated for an hour or so, to ensure that they had taken up as much of the oxygen as possible, the specimen was allowed to drop on to them and the heating continued. In both methods the tube was quickly cooled in air when withdrawn. That the drillings removed most of the oxygen was seen in cases where a surface was first prepared on the scaled specimen. It invariably remained bright after the second heating, the minute particles of oxide found to be present on microscopic examination being insufficient in quantity to give a visible tarnish.

No difference could be observed between the results obtained by the two methods. Heating for 2 hr. at temperatures above the Ac_3 point and up to 970° C. failed to alter the structure. After 5 hr. the network lines seemed to have broadened a little, but even after 20 hr. they were still strong, although less sharply defined. At 1,050° C. this change was noticeable after heating for 1 hr. and more so after 4 hr. After 1 hr. at 1,120° C. the interstices of the network were further reduced in size, the result being similar to that shown in Fig. 6. No trace of the structure could be detected in specimens heated for 30 min. at 1,200° C. Sample No. 3 was tested in the same way, and, while the complete disappearance of the network took place at a somewhat lower point, the elimination was equally characterised by a rapidly increasing rate as the temperature was raised above 1,000° C. Since prepared and unprepared specimens behaved alike, it was evident that the removal of the structure was not due to any interaction with the scale. From the appearance of the

intermediate effects, as indicated in Fig. 6, there could be little doubt that a process of diffusion in the γ-iron was in operation.

Similar experiments were next made at temperatures in the α-range. At 500° C. the structure remained unaltered after heating for two days. No change was observed after a prolonged heating at 700° C. but, after 3 hr. at 800° C., the structure had become much less sharply defined, through the spreading of the network lines as shown in Fig. 6. As the temperature was further raised, diffusion was again found to occur at a rapidly increasing rate, the periods of heating required to obliterate the structure being roughly as follows: At 820° C., 6 hr.; at 840° C., 3 hr.; at 860° C., 1 hr.; and at 875° C., 40 min. Thus the network formed in scaling above the Ac_3 point could be removed by diffusion not only at the higher temperatures of the γ-range, but also at high temperatures in the α-range. Some use of the latter characteristic was made later.

When examining the structures it was constantly noted that the network did not coincide with the boundaries of the α-grains. The two patterns were invariably separate and distinct. Owing to photographic difficulties this has not been shown in many of the illustrations, but instances can be seen in Figs. 2 and 5. Yet, on the other hand, there frequently appeared to be some correspondence between the sizes of the two networks, and a clear demonstration that such was the case was obtained in the following manner. It had been found that a large and stable grain-size could be produced in the Armco iron by heating and cooling it very slowly several times between 850° C. and 950° C.; thereafter the grains could not be appreciably reduced in size by any kind of heat treatment. They were not altered even by drastic quenching, so that it was reasonable to infer the presence of equally large γ-grains at 950° C. Now, when specimens in this condition were scaled at 950° C. a large network structure comparable with that of the α-grains was produced, as illustrated in Fig. 5. These observations led to the deduction that the structure was formed at the boundaries of the γ-grains, and this conclusion was supported by evidence derived in another way.

It is well established that at high temperatures the fracture of iron is intercrystalline. If, therefore, the structure occurred at the margins of the γ-grains, a crack should travel along it. The red-shortness of Armco iron was here useful, in that pieces could be broken with very little distortion, so that the course of the crack could be noted. Short bars, about $\frac{3}{8}$ in. thick, were accordingly scaled at 970° C. for an hour and then quickly broken while the metal was still in the γ-range of temperature. On examination of the surfaces, incipient cracks could generally be found in the neighbourhood of the main fracture, and whenever these were present they followed the network structure, as shown

in Fig. 11. This experiment, like the previous one, clearly yielded strong evidence that the network defines the positions of the γ-grain boundaries, and, since a similar structure will be shown later to form at the margins of the α-grains, the conclusion appears to be beyond question. There is thus indicated a method which may prove useful in studying the recrystallisation of steel as it cools through the Ar_3 point. That a change of this kind occurs, even in quenching, was inferred throughout the present investigation, for the γ-structure never coincided with the α-grain boundaries.

In these first experiments the structure was produced under a scale which was continually growing in thickness. The effect of a stationary scale resulting from a restricted air supply was, therefore, next examined. This was done by quickly heating specimens, usually weighing about 0·5 grm., in a thin-walled silica tube of the size used in the diffusion tests. Its open end was closed at the outset by means of clipped rubber tubing, and after each experiment the silica tube was air-cooled. The same network structure was again obtained at temperatures above Ac_3, but, although well defined, it was not as intense as that formed on pieces heated alongside in an unrestricted air supply, nor did it penetrate into the metal to the same extent. Further, the intensity decreased as the surface area exposed was increased. Under equal treatment, a piece weighing 0·25 grm. gave a much stronger network than a piece weighing 0·75 grm. The structure could be detected after 3 min. at 970° C., and appeared to reach its maximum development there in about 20 min. This is shown in Fig. 4. The continuous layer of a ferritic substance seen in Fig. 7 was here never observed, nor was the structure as permanent. Its intensity gradually weakened when the heating was continued beyond 30 min., until, in 2 hr., deep etching followed by a very light cloth polish was required to reveal the network. Still longer heating made no perceptible difference ; the faint structure persisted, but when the temperature was raised to 1,050° C. a complete disappearance took place within 2 hr.

The condition of a restricted air supply thus gave a structure which diffused in the γ-range at temperatures considerably lower than did the structures produced under free scaling. In the α-range, also, diffusion was found to be more rapid. Specimens were heated for 20 min. at 970° C. and the temperature was then quickly lowered to some point below 900° C. The structure vanished at 850° C. in about 1 hr., and at 880° C. in 20 min., these periods being decidedly shorter than those required for specimens scaled similarly in the open.

That the structure is due to an absorption of oxygen at the boundaries of the γ-crystals is strongly indicated by the fact that scale formation is required to produce it. Moreover, as just

noted, the intensity of the network increased with the amount of oxygen available. Yet, whatever the form may be in which the oxygen exists in the structure, it certainly does not appear to be ferrous oxide that passes into the metal. This conclusion is based on evidence obtained from two different experiments. In the first, two specimens of the Armco iron were heated at 970° C. for 20 min. in closed tubes, after which the temperature was quickly lowered to 860° C. and the heating continued for at least 2 hr. to ensure that no trace of the structure remained. Both tubes were then withdrawn and, when cold, one of them was then opened for a few minutes in order to allow a fresh supply of air to enter. Finally, they were heated again for 20 min. at 970° C. and air-cooled. It was seen on examination that the usual network structure was present on the specimen from the tube which had been opened, but on the other piece no trace could be found. Fig. 17 (Plate XI.) illustrates the appearance of the latter specimen. It shows the scale and the metal surface beneath it entirely free from the structure. The experiment was made repeatedly and always with the same result; no structure was formed when the tube was not opened before the second heating at 970° C.

Now, the condition of a restricted air supply produced a scale on the specimens which was very dark in colour and undoubtedly belonged to the ferrous-oxide phase of Pfeil[1], for it dissolved readily in cold dilute hydrochloric acid. In the above case of the unopened tube two factors would combine to reduce the higher oxide content of the scale to the lowest limit possible at the temperature employed. First, there was the restricted air supply; then, after the available oxygen had been taken up by the specimen, any excess of ferric oxide in the scale over the equilibrium value would, during the long heating, diffuse inwards to the surface of the metal and there be reduced by the iron to ferrous oxide. That such diffusion can occur is demonstrated by the slope of the line *HL* in the diagram given by the above author. It therefore seems clear that the quantity of oxygen required to produce the structure must be greater than that present in a ferrous scale containing only the equilibrium proportion of the higher oxides. In other words, the effect is not due to an absorption of ferrous oxide.

The second experiment was based on the consideration that Armco iron should be saturated with ferrous oxide, if that compound is at all soluble in ferrite, and consequently should not be able to dissolve any more. As was shown by the author some years ago,[2] the small inclusions to be found in this material consist for the most part of mixtures of ferrous oxide and sulphide; the characteristic eutectic given by these two compounds can

[1] *Journal of the Iron and Steel Institute*, 1931, No. I. p. 248.
[2] *Journal of the Iron and Steel Institute*, 1920, No. II. p. 143.

frequently be observed in them. To place the matter beyond question, however, a piece of sample No. 2 was heated in a magnesite crucible to about 1,100° C. and completely melted in a fine jet of oxygen, after which it was allowed to cool down in the air. The metal now contained an abundance of oxide inclusions and the second test was made on a section cut from this material. It comprised the following heat treatment in a closed tube. First, the piece was heated for 20 min. at 970° C., and then for 2 hr. at 860° C. to eliminate the structure. The temperature was next raised again to 970° C. and kept there for 48 hr. in order to make reasonably certain that complete saturation of the iron with ferrous oxide was attained. Finally, before the tube was withdrawn, it was opened and the specimen allowed to scale further in air for 30 min. On examination, it was found that the long soaking at 970° C. had made no difference, for a strong structure was present. That it had formed during the final scaling was proved by the fact that no structure appeared in a duplicate experiment in which the tube was not opened. Here, also, the inference is, therefore, that oxygen in some form other than ferrous oxide is passing into the metal at the γ-grain boundaries.

It was of interest, in this connection, to ascertain the behaviour of Armco iron containing no ferrous oxide. For this purpose, a strip about $\frac{1}{300}$-in.thick was heated in a current of dry hydrogen at 1,200° C. for 2 hr. in order to remove all ferrous and other reducible oxides. A piece was then heated in a closed tube for 20 min. at 970° C. When carefully prepared and etched it gave, as was expected, a distinct network structure.

That the small amount of water vapour in the air might be an essential factor in the formation of the structure was another point which required attention. Tests had shown that the network still appeared when a specimen was heated at 970° C. in a closed tube containing about 5 mg. of water. In order to examine the action of dried air the following experiment was made. A specimen was placed at the bottom of the tube and some phosphorus pentoxide against a pad of ignited asbestos at the open end. The tube was then closed and the lower half inserted, at an inclination, in a muffle at 200° C. By this means a circulation of the air in the tube was maintained by convection sufficient to remove its water vapour content within 3 hr. After remaining there for that time, the tube was inserted in a furnace at 970° C. and held there for 20 min. It was found that the absence of water vapour had made no difference, for the usual network structure was present.

As previously remarked, the occurrence of the network structure is not confined to the γ-range of temperature. It appears also on scaling in the α-range and can then be readily identified by the fact that it is situated entirely at the α-grain boundaries.

This is well illustrated in Stead's example (*loc. cit.*). In studying this α-structure, samples Nos. 2 and 3 were again chiefly used. The effect obtained when a specimen of the Armco iron was heated in air for one hour at 870° C. is shown in Fig. 9. Although the network was not so strong as that given under similar conditions at 970° C. and did not penetrate as far, yet, after a few minutes' heating, it could be detected. The lowest temperature at which the structure could form was not ascertained. At 800° C. it was readily produced; even at 700° C. it was well marked after 1 hr. and remained unaltered when the heating was continued for two days. During lengthy periods of heating above 850° C., however, the structure became less pronounced, and after 24 hr. at 870° C. could no longer be traced. In the specimens treated at 870° C. for a few hours, very minute inclusions of a substance lighter in colour than the scale and evidently rich in iron sulphide appeared in the network. A typical example is given in Fig. 8, which shows these inclusions together with a dark particle of scale at the edge in a specimen which had been heated for 4 hr. at 870° C. This feature was not observed in the γ-structure when the Armco iron was scaled at temperatures not exceeding 950° C. The origin of the particles remains uncertain; they may have been due to a slow precipitation or to a penetration into the metal of the sulphide constituent in the scale.

Since the disappearance of the α-structure during long heating above 850° C. was apparently caused by diffusion, tests similar to those already described on the γ-structure were carried out. In order to form the structure under a standard condition, each specimen was first heated for one hour in air at 870° C., and, after the scale had been removed, it was heated again at the selected temperature, further scaling being avoided by means of the second method (p. 184). The result obtained after 4 hr. at 800° C. is seen in Fig. 10. A comparison with Fig. 9 will show that the network lines had broadened and become less sharply defined. Above this temperature the rate of diffusion began to increase rapidly. After one hour at 850° C. the structure had dispersed to about the same extent as that of Fig. 10, and after $2\frac{1}{2}$ hr. little more than a trace could be discovered. At 870° C. the structure vanished in about $1\frac{1}{2}$ hr. It was noticed throughout these tests that the periods required for diffusion were distinctly longer than those needed for the γ-structure. An explanation of the disappearance of the α-structure after long heating above 850° C. in air can now be given. It would appear to be due to removal by diffusion overtaking the diminishing rate of formation arising from the growing thickness of the scale.

The diffusion of the α-structure in the γ-range was next examined. At temperatures up to 1,000° C. the network was found to persist for long periods. If anything, it seemed to become

stronger owing to a slight broadening of the lines. After 1 hr. at 1,070° C. an effect similar to that seen in Fig. 10 was obtained. Above this temperature the rate of diffusion increased rapidly, but it was again noticed that, as compared with the γ-structure, a rather longer time was required for complete elimination. At 1,170° C. 90 min. heating was necessary, and about 45 min. at 1,230° C. The somewhat slower diffusion of the α-structure in both ranges may be the result of a greater oxygen content, for the structure failed to appear in a restricted air supply, when, as in the previous tests of this kind, specimens weighing about 0·5 grm. were heated in a closed tube of 15 c.c. capacity. Heating periods of from 10 to 60 min. at 870° C. were tried, but in no instance was the α-structure found. Yet when an interval of less than 30 min. was given, and the temperature then quickly raised to 970° C., the γ-structure appeared with an intensity which increased as the time of initial heating was shortened. Whatever the complete explanation may be, this observation seems to indicate that the α-structure requires for its formation a considerably greater concentration of oxygen in the scale than the γ-structure.

Section II.

Thus far the investigation had been confined to a study of the structures given by samples Nos. 2 and 3, and these, although containing but little carbon, were not the purest materials available. Nevertheless, the results led to the conclusion that the network is due primarily to an oxygen content in the scale exceeding that of the ferrous phase requirement. In continuation of the work the behaviour of purer samples was next examined, and it soon became evident that oxygen was not the only factor concerned, for they failed to give the strong effects previously obtained. On scaling specimens of electrolytic iron no α-structure could be found. Except when the air supply was restricted the γ-structure could usually be detected, but it was always weak; at the best its intensity was never comparable with that of the structures formed in samples Nos. 2 and 3 under similar treatment. To observe it great care had to be taken in preparing the surface so as to remove little more than the scale. An example of the weak structure produced in sample No. 1 when heated for 1 hr. at 970° C. is given in Fig. 13, which also shows some of the scale left on the specimen. It was apparent, therefore, that either this purer iron did not absorb oxygen to the same extent as the more impure material, or else that a differentiation of its network was not so well produced by the etching reagents. In either case it was clear that the much stronger structures given by samples Nos. 2 and 3 were due, in part, to the presence of one or more impurities in the metal.

In dealing with the problem as it now stood, the obvious method of procedure was to isolate, if possible, the effect of each of the elements commonly occurring in steel. At the same time it was recognised that a combination of two or more impurities might be involved, and in fact, as the work proceeded, this seemed to become increasingly probable. Attention has been confined, however, to the separate influence of the five elements, carbon, silicon, sulphur, phosphorus, manganese, and the results of this work will now be considered.

Silicon.—This element is clearly not essential, since the structures were formed to a marked degree in samples Nos. 2 and 3 containing little more than a trace. Moreover, they could still be obtained after these steels had been melted in a strongly oxidising flame. On heating a 2·0 per cent. silicon steel for 2 hr. at 970° C., a very fine precipitate occurred in the network. Its composition could not be determined, but in all probability silica was the chief constituent. Riddihough and de Belin have recently published an excellent photograph of this precipitate,[1] which they state is only to be found in scaled steels high in silicon.

Manganese.—It was also apparent that the presence of manganese is not necessary, for only the faintest trace of this element could be detected in the remelted samples mentioned above.

Phosphorus.—A scaled specimen of a basic steel bath sample with a phosphorus content as low as 0·002 per cent. gave a strong structure. Further, when the phosphorus in the electrolytic iron was increased to about 0·10 per cent. by heating a strip in phosphorus vapour and hydrogen, as described by the author some years ago,[2] the structure formed in a specimen heated at 970° C. was no better than that given by the original material. From these and other observations it was clear that the intensity of the effect was not governed by the phosphorus content of the metal, nor was there any evidence to show that the presence of this element is required.

Sulphur.—It had been repeatedly noticed that sample No. 2 gave a distinctly stronger network than sample No. 3 with a lower percentage of sulphur, when the two were equally scaled. Furthermore, it was found that the structure produced at 970° C. in a specimen of electrolytic iron containing 0·015 per cent. of sulphur was more pronounced than any that had been seen in sample No. 1. Attention thus having been directed to sulphur, a piece of sample No. 1 was melted in an oxidising flame with sufficient iron sulphide to make the sulphur about 0·05 per cent. When a section was heated for 1 hr. at 970° C. a network resembling but rather weaker than that seen in Fig. 14 was obtained.

[1] *Journal of the Iron and Steel Institute*, 1931, No. II. p. 446.
[2] *Journal of the Iron and Steel Institute*, 1921, No. I. p. 277.

Although still inferior to the structure given by sample No. 2, it was definitely stronger than that formed in the original material (Fig. 13) under the same conditions. It thus appeared that the intensity depended, in part at least, upon the sulphur content of the metal, and further work indicated that the amount required to produce the best result was not large, being certainly less than 0·06 per cent. Now, since scale also contains sulphur, the next step was to examine the effect of increasing its amount in the scales as they formed on samples which would otherwise give little or no structure. For this purpose three different methods were tried.

Before these experiments are described, however, there are two points connected with the action of sulphur on iron during scaling which need consideration. The first to be noted is the reversible reaction :

$$Fe + SO_2 \rightleftharpoons FeS + O_2,$$

which has been recently studied by Maurer and Bischof.[1] Their work related to open-hearth furnace practice, but the reaction is not confined to the high temperatures there obtaining, even when excess of oxygen is present. This was proved by liberating sulphur dioxide at the rate of about 0·5 c.c. per sec. near a specimen of Armco iron held in the furnace at 950° C. After 1 hr. the scale was found to be rich in sulphide ; it gave a black sulphur print, and, under the microscope, showed a network of a lighter coloured sulphide constituent containing the characteristic oxide-sulphide eutectic. The lowest temperature at which this reaction takes place in air was not ascertained, but below 900° C. the quantity of iron sulphide produced in the same time was much less.

On removing the scale from the specimen heated at 950° C. it was seen that a fairly coarse network of oxide and sulphide was present in the iron, and, after cupric etching, a white border appeared similar to that shown in Fig. 15. This penetration of the metal by the scale at the boundaries of the austenite grains is the other point to be considered. Although the effect was of secondary interest and did not receive the same attention as the network structure, it was repeatedly noticed that the temperature at which the penetration began varied with different steels and with the same steel under different conditions. From the observations made during the investigation the following tentative conclusions were drawn.

(1) When the furnace atmosphere contains sulphur dioxide, and probably other sulphur compounds, the temperature at which the scale begins to enter a given steel at the grain boundaries may be lowered. This was seen in the above experiment, for when the Armco iron was heated in air only, no penetration occurred in an hour at temperatures below 1,050° C. Other instances will be mentioned later.

[1] *Journal of the Iron and Steel Institute*, 1934, No. I. p. 123.

Plate IX.

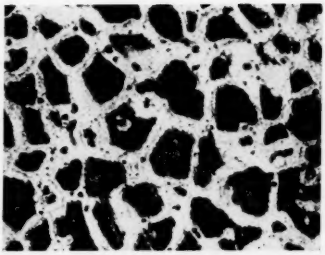

Fig. 1.—γ Structure. Cupric etch. × 100.

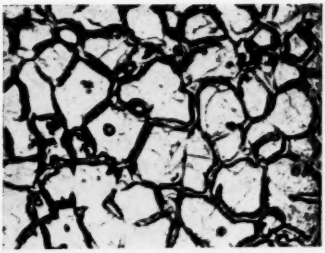

Fig. 2.—Same as Fig. 1. Nitric etch. × 100.

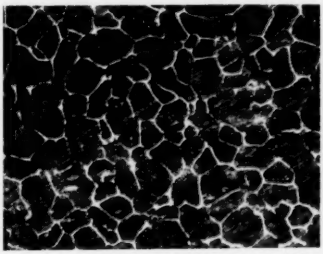

Fig. 3.—γ Structure. Cupric etch. × 100.

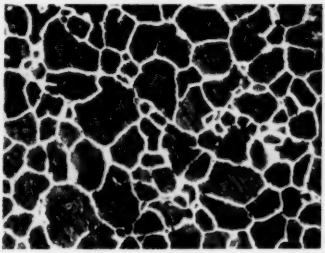

Fig. 4.—γ Structure. Cupric etch. × 100.

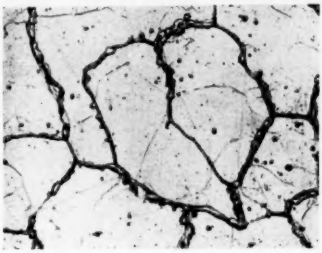

Fig. 5.—γ Structure. Picric etch. × 70

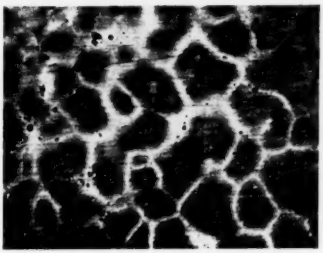

Fig. 6.—γ Structure, diffusing. Cupric etch. × 100.

[*Whiteley.*

[*To face p.*192

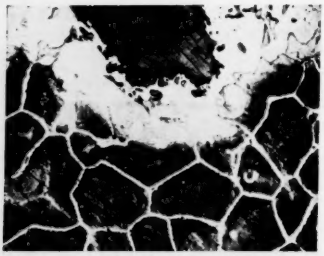

FIG. 7.—γ Structure and Layer. Cupric etch. × 100.

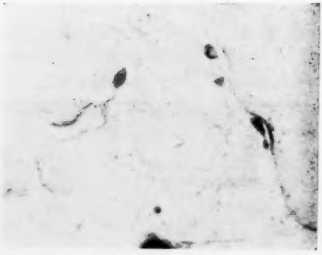

FIG. 8.—Inclusions in α Structure. Picric etch. × 900.

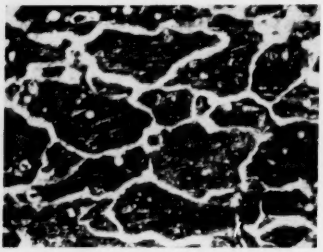

FIG. 9.—α Structure. Cupric etch. × 150.

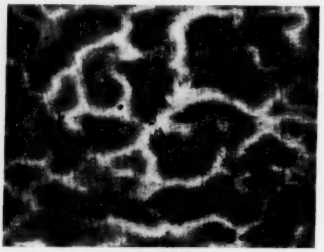

FIG. 10.—α Structure, diffusing. Cupric etch. × 150.

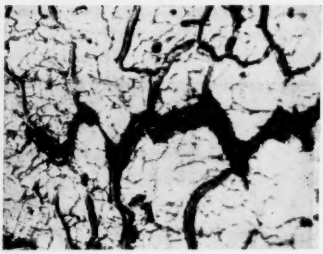

FIG. 11.—γ Structure and Crack. Nitric etch. × 100.

FIG. 12.—γ Structure, penetration. Cupric etch. × 100.

[*Whiteley.*

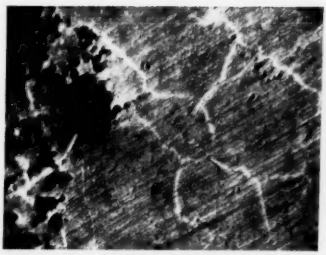

FIG. 13.—γ Structure, electrolytic iron. Cupric etch. × 150.

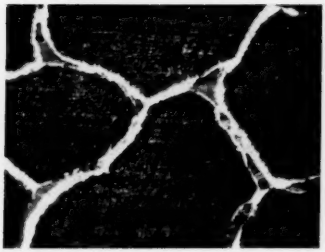

FIG. 14.—γ Structure electrolytic iron with sulphur. Cupric etch. × 300.

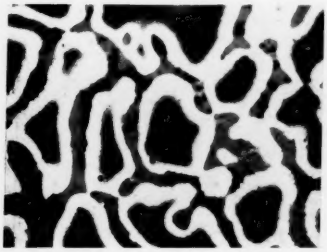

FIG. 15.—γ Structure and Scale Penetration. Cupric etch. × 150.

FIG. 16.—γ Structure in Armco Iron with sulphide. Cupric etch. × 300.

FIG. 17.—Armco Iron, no γ structure. Nitric and cupric etch. × 100.

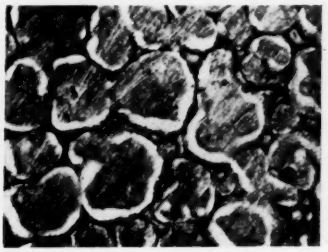

FIG. 18.—Armco Iron, γ structure with sulphur. Cupric etch. × 150.

[*Whiteley.*

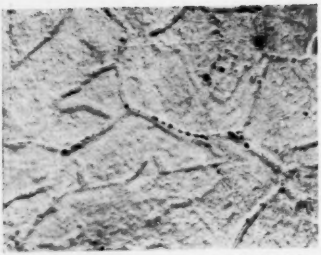

FIG. 19.—Pure Iron, γ structure. Picric etch. × 300.

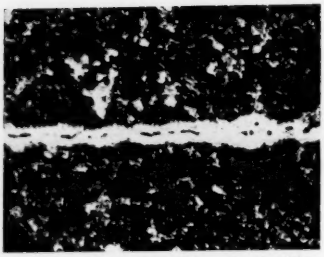

FIG. 20.—Weld in Steel Pipe. Cupric etch. × 100.

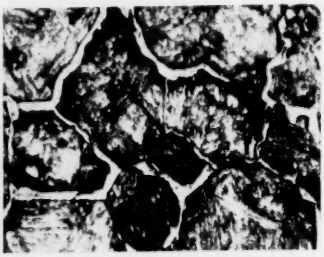

FIG. 21.—γ Structure and Martensite. Nitric etch. × 300.

FIG. 22.—γ Structure and Pearlite. Picric etch. × 300.

FIG. 23.—γ Structure at Weld. Picric etch. × 150.

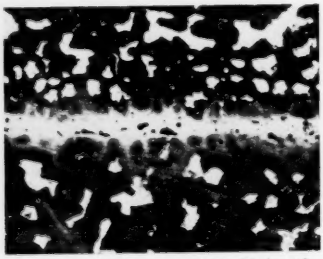

FIG. 24.—γ Structure, carburised. Picric etch. × 150.

[*Whiteley.*

[*To face p.* 193.

(2) Scale penetration is retarded by the presence of carbon in the metal. An effect of this nature is perhaps to be expected, since carbon will tend to reduce the intruding oxide, provided that it is brought to the surface in sufficient amount by diffusion. In support of this conclusion one experiment may be mentioned. A composite sample was prepared by welding together two steels containing 0·2 per cent. and 1·50 per cent. of carbon, and about 0·06 per cent. of sulphur. A specimen was then heated for an hour in air at 980° C. and it was found that, while boundary penetration of the scale was considerable in the low-carbon area, scarcely any had taken place in the part high in carbon.

(3) The lower the sulphur content of the metal the higher is the temperature at which boundary penetration begins in air. For instance, no indication of this scale intrusion could be seen in samples of electrolytic iron heated for 1 hr. at 1,100° C., but when the sulphur in the material was increased to 0·05 per cent. by the addition of iron sulphide, some penetration was observed in specimens heated for 1 hr. at 970° C. Under the latter treatment, steels with less than 0·035 per cent. of sulphur were free from scale intrusions at the grain margins. They began to be visible in quantity at about 1,050° C., chiefly as light coloured particles undoubtedly rich in sulphide. Their presence in sample No. 2 can be seen in Fig. 1 ; under high magnification they resembled the inclusions illustrated in Fig. 8. As the temperature was further raised the penetration grew in extent until, at 1,250° C., an almost complete network was obtained. Fig. 15 gives the appearance of an etched surface of sample No. 2 after the specimen had been heated for 20 min. at the above temperature. The γ-structure is evident as a white border to the network of penetrating oxide and sulphide. On examination of a cross-section it was found that the scale extended well into the metal in the same way as the structure shown in Fig. 12. At about 1,400° C. a still heavier penetration occurred, but the white margin was much narrower. Apparently the rapidity of scale formation and intrusion prevented growth of the γ-structure by removal of the metal containing it. With higher percentages of sulphur in the steels, penetration began at temperatures well below 1,050° C. In two steels, one containing 0·12 per cent. and the other 0·27 per cent., it was quite pronounced after 20 min. at 950° C., and could be detected even at 920° C.

As stated earlier, all attempts to make the γ-structure advance into the metal beyond the short distance shown in Fig. 12 failed, and the reason for this now becomes clearer. At temperatures up to 1,000° C. the speed of its dispersion by diffusion into the austenite grains is extremely slow, but, on the other hand, a fresh surface is constantly forming as the scale grows in thickness. It is true that this proceeds at a diminishing rate, but that means

the transmission of less oxygen to the metal, replenishment of the structure being thereby retarded. Above 1,000° C. the increasing rates of diffusion, scale formation and its penetration will all combine to keep the structure in close proximity to the surface.

Since the network structure can appear and persist free from scale penetration, as, for example, in Armco iron below 950° C., there can be little doubt that, when penetration does occur, the structure is already present. Whether the sulphide-oxide inclusions in such cases are due to a direct intrusion by the scale or to a precipitation from the solid solution of the network remains uncertain. It should be remarked, however, that the temperature at which penetration ceased in the high-sulphur steels, scaled in air, was not far above 900° C., which is near the melting point of the ferrous oxide-sulphide eutectic. As previously mentioned, incipient penetration can be detected by the presence in the network of fine particles of a light coloured sulphide, and it was repeatedly noticed, when the process had proceeded further, that the tips of the advancing tongues of scale contained the least proportion of oxide. These observations thus seem to suggest penetration rather than precipitation, the eroding agent being the liquid part of the scale. The subject is one which calls for further study, especially since the character and quality of the surface finish on steel products may, in some instances, depend largely on the extent of this scale penetration during the final heating before rolling.

To return to the effect of sulphur on the intensity of the network structure, the first of the three methods used for sulphurising the scale was as follows: A specimen of sample No. 1 was placed at the closed end of a silica tube against a pad of asbestos containing about 0·2 grm. of granular iron sulphide. The open tube was then inserted in the furnace at 970° C. and held there for 1 hr. By this means the sulphur content of the scale was raised through the reaction of the iron with the sulphur dioxide liberated from the ignited sulphide in the asbestos. The result was that a certain amount of scale penetration occurred, and, when the specimen was etched, a fairly strong structure appeared, particularly in the neighbourhood of the oxide-sulphide inclusions. An area of this description is shown in Fig. 14. The increased intensity of the network will be seen by comparison with Fig. 13, which shows the structure given by sample No. 1 under similar treatment but in air only. This experiment was done several times at temperatures between 950° C. and 1,000° C., and in each instance the presence of sulphur dioxide caused a definite improvement, the best effects being obtained at 970° C. and above.

The second method of treatment was to heat a specimen of sample No. 1, weighing about 0·1 grm., with approximately

2 mg. of sulphur at 970° C. for 1 hr. in a closed silica tube. This, also, was repeated several times and with consistent results. Some penetration of the scale again took place, and the γ-structure was observed, after etching, as a white border surrounding these inclusions. Under the condition of a restricted air supply, however, the intensity of the structure was less than that given by the previous method. An attempt was next made to induce the α-structure to form on Armco iron in the closed tube by this means, but, while the scale was found to be rich in sulphide after 30 min. at 870° C., the structure could not be detected. The γ-structure obtained on this iron after 1 hr. at 970° C. is shown in Fig. 18. It will be seen that the addition of sulphur has caused the network to spread well into the austenite grains, as if the rate of its diffusion in the γ-range had been accelerated. This feature frequently appeared when the structure was formed under a scale with an increased sulphur content.

In the third method the effect of placing a layer of iron sulphide on the scaled surface was tried. A specimen of sample No. 2 was heated for 20 min. in a closed tube at 960° C., after which the temperature was lowered to 860° C. and the heating continued for 2 hr., in order to eliminate completely the γ-structure by diffusion. The tube was then cooled, the specimen removed and a very thin layer of wet finely ground iron sulphide was spread over its surface. When this layer was dry it was found to adhere sufficiently well to remain undisturbed by gentle tapping. Some Armco drillings were next placed at the bottom of the tube, with the specimen at the open end. The tube was closed and the drillings were heated for 1 hr. at 980° C., after which the specimen was quickly moved on to them by tilting the tube. Finally, a further heating was given for 45 min. When the specimen was inspected it was seen that the scale and sulphide had fused together on the surface. Several such experiments were made and invariably, after etching, the sulphide-oxide penetrations present were surrounded by a white border. In some instances a complete, though rather weak, network appeared as shown in Fig. 16. No trace of the γ-structure could be detected on specimens treated in the same way but without the sulphide layer. Whether the sulphide acted directly on the metal to produce the structure, or indirectly by liberating a small amount of sulphur dioxide, was not ascertained. It was clear, nevertheless, that sulphur could induce the structure to form under conditions where it would not otherwise occur. Similarly, when a layer of sulphide was placed on a specimen of sample No. 1 and the piece was heated in air for 1 hr. at 980° C., a network as strong as that shown in Fig. 14 was produced. It should be mentioned that diffusion tests at 860° C. were carried out on the structures given by all three methods, and they were found to disappear within 2 hr.

The conclusion to be drawn from these experiments is that the γ-structure can be intensified by increasing the sulphide content of the scale. Further, it seems evident that the sulphide acts either by dissolving in the iron at the austenite grain boundaries or by facilitating the entry of more oxygen. The latter explanation is, perhaps, the more probable, since, if sulphide is at all soluble in iron, the austenite should be saturated after long heating. At any rate, the structure appeared as usual on two Armco pieces which had first been soaked for 16 hr. at 860° C. and 960° C., respectively, in closed tubes and then scaled at 960° C. by opening the tubes without withdrawing them from the furnace. The same result was given by the fused electrolytic iron to which 0·05 per cent. of sulphur had been added.

Since sulphur had been found to have an intensifying effect, the question arose as to whether the structure would still form in iron entirely free from it. Unfortunately such material was not available, but Dr. Desch kindly sent the author a small specimen stated to be purer than any iron obtainable commercially, and this, on being scaled for 1 hr. at 970° C., gave the weak but distinct network shown in Fig. 19 (Plate XII.). The inference is, therefore, that the presence of sulphur is not essential. It may be remarked, in passing, that when steel is welded either by wash-heating, or by the use of any other flame containing sulphur, the γ-structure is frequently to be seen at the weld junction. Cupric reagents reveal it as a white band, which is usually brought out in strong relief by both picric and nitric acids. Fig. 20 is an example. It shows the weld in a pipe made of mild-steel plates joined together by means of a water-gas flame. The structure may often be observed, also, along rokes and seams which have originated in the ingot and have afterwards been partially welded during either reheating or the final rolling.

Carbon.—In order to ascertain the effect of this element, specimens of the electrolytic iron were carburised to about 0·4 per cent. by heating them for 2 hr. at 950° C. in a closed tube with some charcoal prepared from pure filter paper. They were then scaled in air at 970° C. for periods ranging from 15 min. to 1 hr. After the shorter heatings, some carbon was still to be seen at the surfaces as pearlite, but no γ-structure could be detected. The specimens subjected to longer heating were more decarburised, and picric acid brought out a weak structure on them which disappeared when the specimens were etched further with nitric acid. It was concluded therefore that carbon alone did not cause any increase in the intensity.

During the investigation various steels with carbon contents from 0·03 per cent. up to 2·3 per cent. were tested. They all, without exception, gave a good γ-structure when scaled in air at 970° C., provided that sufficient time was allowed in heating for

at least partial surface decarburisation to occur. That given by sample No. 4, quenched after 1 hr., is shown in Fig. 21. It will be noticed that the network enclosing the martensite is very sharply defined. The extent to which the structure advanced into the metal was found to depend upon the depth of surface decarburisation. With the higher carbon specimens the outward diffusion of the carbon tended to prevent any appreciable penetration. This was also seen when different steels were heated for 15 min. in the closed tube at 970° C. In the restricted air supply which obtained, a steel with 0·10 per cent. of carbon gave a pronounced structure. With 0·20 per cent. present, however, the effect was much weaker, and, in order to reveal it, great care was needed in the preparation of the surface. No structure could be detected in steels containing more than 0·45 per cent. of carbon, although a film of dark scale was on them. Additional evidence was thus afforded that the structure is primarily due to an absorption of oxygen.

In the foregoing tests on the specimens low in carbon, the pearlite at the surfaces was almost entirely within the meshes of the network. The same feature became apparent when the specimen with the structure shown in Fig. 1 was carburised. It was heated with charcoal in a closed tube for 15 min. at 960° C. and cooled to 600° C. in 5 min. While about 0·2 per cent. of carbon was present at the surface, no pearlite was on the network, which, though weaker, could still be detected. Fig. 22 shows both the pearlite and the network in this specimen. From these observations it was inferred that the carbon had moved out of the γ-structure as the temperature fell from Ar_3 to Ar_1, but, in order to obtain more definite evidence on this point, the following experiment was made.

A cylindrical piece of sample No. 3, 1 in. long and a full ½ in. in diam., was heated in air at 970° C. for 2 hr. It was then rapidly cooled and the coating of scale removed, as far as possible, so as to leave the γ-structure below intact. Another piece of the sample was forged into a bar of 1 in. square section and a hole was bored down the centre with a ½ in. drill to within ⅜ in. of the base. The scaled cylinder was now inserted in the bar and the hole was then closed by hammering in a tightly fitting plug of the same steel. Finally, bar and cylinder were heated to about 1,000° C. and welded together by forging them down to a thickness of ⅜ in. A weld sufficiently good for the purpose resulted. When a section was etched, the γ-structure, formed in the cylinder, appeared at the weld as a band with a flattened fringe on the cylinder side, as shown in Fig. 23. This fringe was, of course, due to the penetration of the structure along the austenite grain boundaries during scaling at 970° C.

The section was next carburised with charcoal at 960° C. and air-cooled. On examination, about 0·25 per cent. of carbon was found to have been absorbed at the surface. It was evenly distributed and the γ-structure at the weld was not distinctly apparent as a ferrite band, presumably because the rate of cooling had been too rapid. The specimen was, therefore, reheated to 900° C. in a closed tube and cooled more slowly, the time occupied in reaching 700° C. being about 10 min. It was now obvious that a movement of the carbon away from the γ-structure had taken place. Fig. 24 shows the band at the weld and the white areas of pearlite outside it, as differentiated by cupric etching. The fringe seen in Fig. 23 was no longer present, nor did the γ-structure stand up in relief when etched with picric or nitric acids. This modification of the structure after carburisation was repeatedly noticed and was possibly the result of a removal of part of the oxygen content. If so, a residue easily detectable by the cupric reagent was always left.

Several such experiments were made on specimens from the welded piece, the conditions being changed so as to produce varying degrees of carburisation. In all cases, a moderate rate of cooling gave a ferrite band at the weld, free from carbon except for a very thin line of carbide particles along the centre. This feature appeared after a picric acid etch, and is not shown in Fig. 24. The movement of the carbon seemed to have taken place from the intermediate zones on either side rather than from the centre of the band outwards. It was clear, nevertheless, that carbon tended to migrate from the γ-structure as it cooled. The same conclusion was reached by Thompson and Willows[1] in carburising, at 900° C., strips of mild steel which had been scaled in air at 1,000°–1,200° C. They found below the carbonless skin a band of pearlite distinctly greater in quantity than that in the original material. Those authors, following Le Chatelier and Bogitch,[2] contend that the ordinary banded structure of rolled and forged steels is due to a differential solid solution of oxygen in the ferrite bands. It must be admitted that the results arrived at in the present investigation lend considerable support to this view, provided that the intensifying effect of sulphur is taken into account, for the ferrite bands and the α- and γ-structures have the following characteristics in common :

(1) They resist the attack of cupric reagents and can thus readily be detected.

(2) They diffuse in the α-range with increasing rapidity as the temperature rises above 800° C. With the banded structure this can, of course, only be observed in steels very low in carbon. In rolled sheets of such dead soft material most of the bands

[1] *Journal of the Iron and Steel Institute*, 1931, No. II. p. 170.
[2] *Comptes Rendus*, 1918, vol. 167, p. 472.

disappear fairly quickly when the metal is heated a little above 800° C.

(3) They vanish when heated in the γ-range between 1,100° C. and 1,200° C.

(4) The main feature of the banded structure, in low- and medium-carbon steels, is the formation of ferrite bands during cooling, due to the migration of carbon out of them. It has been shown that this is also a characteristic of the γ-structure.

In conclusion, the author wishes to express his indebtedness to Dr. C. H. Desch, F.R.S., and Dr. T. Swinden for samples of pure iron, and to Mr. F. F. Hunting for a supply of Armco iron.

DISCUSSION.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), said he had read the paper with very great interest and he thought it would be clear to everyone that Mr. Whiteley had a very happy knack of carrying out most interesting researches on what might be called the old Stead method. Undoubtedly the work described was very interesting, as were the deductions, but there were two comments which he would like to make.

In the first place, he (Dr. Hatfield) regarded the cupric etching reagent used as likely to be misleading. He had done a great deal of work with it himself some years ago and had found it most unreliable ; it was not a quantitative exact scientific means of attack. That was the impression which he derived from his experience, and, as an instance, if one looked at Fig. 6 or, better still, at Fig. 1, where there was the white network of a constituent obtained by the cupric etching method, one would see running through that white constituent bands of non-metallic inclusions. Looking back to his own experience with that reagent,[1] he would be inclined to think that that white etching effect, or rather the local absence of a deposition there, was due to the indirect action of the inclusions in preventing the deposition of copper, rather than to the presence of a constituent which was disclosed by that etching method. He merely advanced that idea for the comments of the author.

The other point arose at the end of the paper, where the author said : "Those authors, following Le Chatelier and Bogitch, contend that the ordinary banded structure of rolled and forged steels is due to a differential solid solution of oxygen in the ferrite bands. It must be admitted that the results arrived at in the present investigation lend considerable support to this view." He (Dr. Hatfield) could only say that Le Chatelier and Bogitch had no exact evidence for the assumption that there was a differential distribution of oxygen in the banded areas in mild steel, and personally he knew of no evidence in support although he had tried to find it in the past.

With regard to the general proposition of oxidation along the grain boundaries of the γ-iron condition at high temperatures, there was, of course, clear support for the practical contention of Mr. Whiteley, but one did not need Mr. Whiteley's method of approach ; one could find by ordinary methods of examination in the cross-section of the material the permeation of the scale along the grain boundaries, but he had found no evidence of the

[1] *Journal of the Iron and Steel Institute*, 1915, No. I. p. 182.

solution of oxide in the steel beyond the actual surfaces of contact by the permeating oxide which seemed to develop between the crystal boundaries. However, there would be general agreement that the paper represented a very interesting piece of work and would cause people to think again on the subject of the interesting points which the author discussed.

Dr. C. H. Desch, F.R.S. (Vice-President, Teddington), said that Mr. Whiteley had continued the Stead tradition, which consisted in making a few very simple experiments with the most elementary apparatus and obtaining results of the highest importance. The author had made out a very strong case for the structures in question being due to oxygen, but the action was evidently complicated, and now that those structures had been obtained by scaling, it seemed well to emphasise the real importance of starting with pure iron and trying the successive action of oxygen and of sulphur and other elements on that pure iron, and working out quantitatively their relations. That it was due to oxygen seemed to be shown by the fact that the structure was obtained even on a sample of pure iron, but that sulphur co-operated was also shown by the great intensification of the structure exhibited in the samples of less pure iron.

Dr. Hatfield had referred to the unreliability of the cupric reagent. Personally he did not agree with that, but, even if it were admitted that the cupric reagent was unreliable, the fact that when those non-metallic inclusions were present one found a difference in structure in their neighbourhood produced by the cupric reagent surely showed that there was some local difference in the metal.

A good deal of work had been published to show that the solubility of oxide in ferrite was practically nil, but one could not reconcile that with experience. There was a reference in the paper to some work which de Belin and Riddihough did while he himself was in Sheffield. He had some of their photographs which showed clearly that in the neighbourhood of those boundaries there was not only a different chemical composition but an increased hardness. One could polish it and bring up the boundaries into relief, and he did not see how to account for what was found unless there were oxide in solid solution. He was not very much worried by the fact that ferrous oxide alone would not cause the passage into the metal; it might be that extra oxygen pressure was necessary. He felt very strongly that the structures in question were essentially due to oxygen, however, whatever might be the effect of other co-operating elements, and when the paper by Professor Andrew and Mr. Richardson[1] was discussed later it would be found that the facts

[1] This Journal, p. 129.

brought forward by Mr. Whiteley had a very close bearing on the behaviour of spring steels. It was obviously important to have a thorough investigation of the relations between pure iron, oxygen and sulphur and a few other elements. The matter would have to be approached in a synthetic way now that Mr. Whiteley had made such a very interesting approach from the other side.

Professor J. H. ANDREW (Sheffield) said that, like Dr. Desch, he had read the paper with very great interest and thought it contained some very important work. He would like to compliment the author on his micrographs, which, he understood, were taken with a microscope which did not represent the latest type in use ; but, like all Mr. Whiteley's work, the micrographs were of very first-class quality.

With regard to the question of oxygen in steel, a considerable amount of the work in that direction had been done in Sheffield, as the author knew, and some very interesting results had been obtained with regard to the solubility of oxygen. What he could not quite understand was why, in the first instance, the oxygen should go to the boundaries, and then upon heating at higher temperatures, in either the α or γ regions, all that oxygen diffused and went into solution. Was there no precipitation of it again at lower temperatures, and could the boundary phase never be retrieved when once the oxygen was diffused ?

He supposed that there was no possibility that the author had polished off that particular layer after his second diffusing treatment ? He would like to know the amount of material removed from the surface after polishing the second time, and whether there was any possibility that the second polishing removed the oxidised surface. That it was possible to have a large quantity of oxygen in solution in steel could be shown by examining weld-metal. One could obtain a weld metal which looked perfectly sound and consisted of pure ferrite grains, and yet contained as much as 0·14 per cent. of oxygen, and the weld would be sound in every respect.

With regard to the question of sulphur, he found it difficult to see how sulphur could take part in what occurred. Sulphur in itself was a deoxidiser, and if it were present in the grain boundary constituent it would be left at the boundaries when the oxide had diffused. It was difficult to see how the sulphide part of the constituent could diffuse along with the oxygen, and one would expect it would be left after the oxygen had diffused as a constituent round the grain boundaries. The whole action was like that of cementation ; it was a question of oxygen formation being rapid and diffusion being slow, just as with cementation carbide formation was rapid and carbide diffusion slow.

Dr. T. SWINDEN (Sheffield) said that some months ago he had had the pleasure of discussing this subject with Mr. Whiteley, and in addition to sending him some samples of material, he had also carried out experiments on the lines indicated by Mr. Whiteley, with particular reference to pure materials. The analyses of the three materials examined were as follows:

Material	C.%	Mn.%	Si.%	S.%	P.%	Cu.%	Ni.%	Cr.%	As.%
A	0·03	0·08	Trace	0·023	0·007	Nil	0·02	Nil	0·030
B	0·015	0·01	Trace	0·003	0·005	Nil	Nil	Nil	0·009
C	0·04	0·10	Trace	0·025	0·015	0·05	Nil	Nil	0·025

Material *A* was a cast of special pure basic open-hearth steel, *B* was carbonyl iron, and *C* Armco iron.

Considerable difficulty was encountered in developing the structure described by Whiteley, particularly in the carbonyl iron. He was, however, ultimately successful in finding the structure in the basic open-hearth steel and Armco iron after heating for about 1 hr. at 950° C. Under these circumstances, the thickness of the layer revealing this structure was extremely small and did not exceed 0·001 in. Best success was obtained by polishing the sample at a very small angle to the original surface, following which the structure was revealed by etching in picric acid. It took the form of a light-coloured constituent which had separated out in the form of a network.

The extreme thinness of the layer exhibiting the network structure gave one the first impression that this was essentially a structure in the scale itself, and the speaker still felt, notwithstanding Mr. Whiteley's brilliant exposition, that it was difficult to accept the hypothesis put forward by him. He (Dr. Swinden) did know, however, of cases where the skin of a bloom or billet had a tendency to develop a certain type of craziness which did not appear to be connected in any way with the general quality of the steel. Such cases would in future be examined with increased interest as a result of the work now presented by Mr. Whiteley.

Dr. L. F. C. NORTHCOTT (Woolwich) thought the author was to be complimented on a very interesting paper, but said that there were one or two points which, at any rate to his mind, were not quite clear.

Taking the least important point first, he asked whether Mr. Whiteley had any particular reason for using specimens of such small size. Where the size of the specimens was given, Mr. Whiteley described them as weighing 0·75, 0·5, 0·25, and 0·1 grm. and being 0·03 in. thick. Personally he had done some scaling experiments, and the work of clearing the scale and seeing the structure of the iron free from scale was of some difficulty.

He thought that, in view of the small samples which he had used, Mr. Whiteley was to be complimented on getting any micrographs at all, and certainly on getting such excellent ones as he had in fact obtained.

The second and rather more important point was really an enquiry as to the form in which the author considered the oxygen went into the iron. He gathered from Mr. Whiteley's opening remarks that he was not certain what the form was. After reading the paper, he himself was of opinion that oxygen was responsible for the structures, but he saw no reason why the oxygen should not diffuse in the iron in the form of ferrous oxide. In sulphur-free material the oxygen might be present either as free oxygen or as ferric oxide, and in sulphur-bearing material as gaseous sulphur dioxide.

With regard to what Professor Andrew had said about the cementation process, he thought it highly probable that the penetration of oxygen into the metal in the first instance was a gaseous reaction, but the author's experiments emphasised that ferrous oxide was not important. He thought that needed further confirmation. In the iron which originally contained little or no oxygen he could not imagine that the presence of ferric oxide would be responsible ; he would certainly have thought that there would at least be a layer of ferrous oxide and that ferrous oxide would play the important part. In the experiment which the author conducted on obtaining Armco iron with an abundance of ferrous oxide inclusions, which he treated at 970° for 48 hr., he had already stated that there was considerable difficulty in causing diffusion at or just about the temperature of the critical range. Personally he thought it was difficult for a solid inclusion to diffuse in either steel or iron, and he thought it was possible that the iron was not saturated with oxygen as ferrous oxide or anything else ; in that connection he would draw the attention of the author to the paper presented before the Institute three years ago on veining and sub-boundary structures. He thought the two papers were complementary. The present paper dealt with the putting of oxygen into iron, and the other paper with what happened to the oxygen after it had got into the iron. An attempt was made in that paper to show what had been subsequently proved by further experiments, or at any rate what further experimenters had reported, both in Germany and in America, namely, that the solubility of oxygen in iron decreased with decreasing temperature. He asked if the author had found any structures, such as the sub-boundary structures, which were due to the precipitation of the oxide under certain conditions of cooling. That would be of interest, because from a cursory examination, especially of Fig. 11, he was not quite sure that some of that network was not a network inside the α crystals.

The third point was an enquiry as to the author's opinion of the constitution of the network. Dr. Hatfield had made some critical remarks about the cupric reagent, and personally he was not certain that the small size of the author's specimens might not increase the difficulty of the irregularity of the oxide penetration or the scaling effect. The author said that the cupric reagent was used because it showed the network effect better than the other reagent, especially for photographic work, and in that connection it might be suggested that the author might derive advantage from using a larger specimen which was sectioned after scaling in a tapering manner; that might give a better view of the results of the scaling.

The disadvantage of the cupric reagent, apart from the irregularity—although he did not think there was any need with a properly prepared specimen for any irregularity to occur—was that it showed in one phase slight differences in composition which were not clearly defined. The network shown by the author with his cupric reagent might well be passages in the iron phase higher in oxygen. He was not at all certain that that was what constituted the network. With the picric reagent and the nitric acid reagent a fairly clearly-defined boundary was shown, and that boundary could be due either to a difference in orientation of the crystals, which was unlikely, since it occurred in a single crystal, or to the precipitation of a constituent or the presence of a constitutent; he asked if the author had any further views on the constitution of the network.

His fourth point was to ask the author if any further work was being done or could be done by him on the effect of sulphur in the complete absence of oxygen.

Dr. C. A. Edwards, F.R.S. (Swansea), said there was one point on which he would like the author to throw a little more light. As he understood it, Mr. Whiteley suggested that the disappearance of the network on heating was due to the solution of the oxygen in the ferrite. In view of the facts referred to by Mr. Whiteley, he (Dr. Edwards) thought that it was well within the bounds of possibility that the oxygen was really removed on heating by the carbon present in the steel. This would, no doubt, occur, even with carbon as low as 0·02 per cent. or less, and he thought that there could be no doubt concerning the accuracy of Mr. Whiteley's views to the effect that the network was due to oxygen. Further, it would be anticipated that the presence of sulphur compound would accelerate the rate at which this network was formed, simply because the increase in the furnace gas increased the rate at which scaling took place.

Dr. A. McCance (Member of Council, Glasgow) said that Mr. Whiteley had the faculty with a few acute observations of raising

questions of the very greatest importance in practical work, and his present paper was no exception and was indeed a very excellent example of his skill in that direction. The association of sulphur in ghost lines, for example, had always been somewhat difficult to explain, and it was possible that the present paper, if it did not give the whole explanation, at least gave a clue to what was taking place. Another class of defect, surface cracks, was associated with marked scale absorption. Efforts had been made to discover just what differences existed between different classes of steel with regard to that fact, and he must confess that it had not been possible to make very much headway in regard to that problem. They had not, however, considered the possibility of sulphur interference in that respect. When heating up any steel article in furnace gases, as Dr. Edwards mentioned, sulphur absorption took place in some cases to a very marked extent, and it was possible that the scale absorption which was noticed and which was associated with certain defects was a secondary effect due to sulphur absorption. They had not noticed definite sulphur absorption in those cases, but it had not been looked for particularly, and it might be found, in the light of the information contained in the present paper, that the mechanism of the reaction was that scale was being absorbed as a secondary effect of sulphur absorption. That would prove, he thought, to be a matter of some importance.

Another point was that bad welds, as a rule, were associated with an excessive amount of scale absorption. As a rule that had been ascribed simply to surface scale which had not been removed sufficiently prior to the welding operation, but it might be that it was not possible to remove it owing to its being associated with sulphur absorption. All those questions should have further light thrown upon them as the result of what he regarded as a most important piece of work.

CORRESPONDENCE.

Messrs. G. A. de Belin and G. T. Richardson (Sheffield) wrote that some illustrations which they had prepared in 1932, in connection with the continuation of the work of Riddihough and de Belin, afforded interesting confirmation and amplification of some of the details of Mr. Whiteley's paper. On p. 183 Mr. Whiteley mentioned the presence of a ferritic layer, resisting the cupric reagent, underlying the scale, and on the same page he referred to the tapering of the veining as it travelled inwards.

Fig. A (Plate XIIa.) showed a transverse section through the scaled surface of a specimen of electrolytic iron which had been held at 950° C. for 10 min., and then heated in graphite

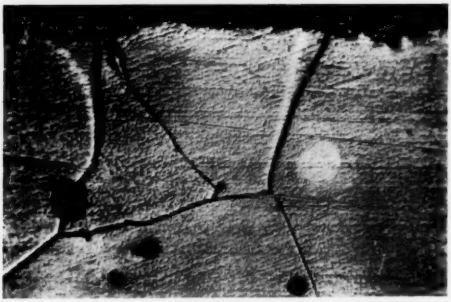

FIG. A.—Transverse Section through Scaled Surface of Electrolytic Iron, heated at 950° C. for 10 min., then in graphite at 720° C. for 2¼ hr. Etched. × 1,000.

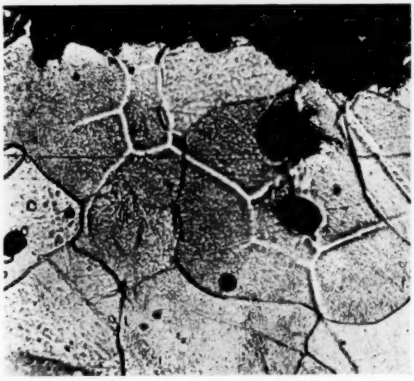

FIG. B.—Electrolytic Iron, as-rolled. Polished and etched. × 1,000.

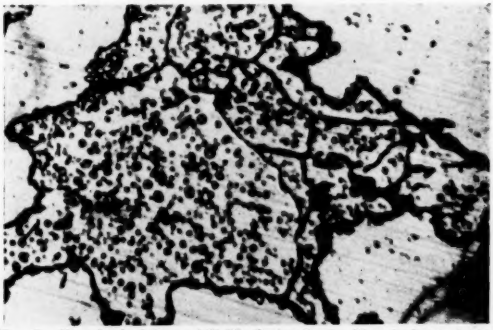

FIG. C.—Decarburised Zone of Si–Mn Spring Steel. Unetched. × 2,000. (Micrographs reduced to four-fifths linear in reproduction.) (See de Belin and Richardson's correspondence.)

[*Whiteley, correspondence.*

[*To face p.* 206.

for 2¼ hr. at 720° C. to promote diffusion of the boundary solid solution. The result clearly confirmed Mr. Whiteley's experiments. This micrograph also amplified his notes on p. 190 on the development of the γ structure in scaled electrolytic iron.

On p. 185, Mr. Whiteley noted that photographic difficulties prevented the illustration of the non-coincidence of the γ-veining with the α crystal boundaries. The writers were fortunate in obtaining a very clear picture of that phenomenon. Fig. B showed a polished and etched surface of electrolytic iron in the as-rolled condition. The black mass was a patch of scale which had not been ground away, and the abnormal boundaries were visible as a bright network which was clearly independent of the α crystal boundaries.

Figs. A and B were also interesting from the point of view of practical metallography, in that they revealed the boundary constituent without the use of special reagents, and indicated a comparative insusceptibility to acid attack. The specimens shown were etched for 30 sec. in 2 per cent. nitric acid in alcohol. The lighting was by plane glass vertical illuminator, slightly de-centred in Fig. A, and slightly diaphragmed in Fig. B.

On p. 191 Mr. Whiteley suggested that the precipitation characteristic of the decarburised zones of silicon steels was mainly silica. Fig. C, a high-power micrograph of such an area, unetched, confirmed that suggestion. It was seen that the particles were not black or grey, as would be oxides, sulphides, or silicates, but were spherical, in relief, and white, or highly polished. They were strongly reminiscent of grains of sand.

AUTHOR'S REPLY.

Mr. WHITELEY, in reply, said that Dr. Hatfield appeared to have encountered difficulties with cupric etching, but he would submit that that was scarcely a sufficient reason for a general condemnation. The criticism which he (Dr. Hatfield) had made in 1915, to which he had referred, was the outcome of a comparison of results on certain kinds of steel given by two reagents —namely, Rosenhain's and Stead's—neither of which had been used in the present work. He (Mr. Whiteley) was of the opinion that Dupuy's reagent, the one he had employed, was the most reliable. Rosenhain's, in particular, was strongly acid and rather drastic, although, on occasion, it could be very useful. Probably cupric etching needed more practice and experience than the ordinary acid etching, but, when once this was acquired, he had no doubt that the results were both "exact and scientific." Cupric reagents frequently brought out in greater contrast features which could, by careful examination, be also detected by either

picric or nitric reagents, and this fact alone should be sufficient to prove them trustworthy. The latter reagents were of greatest service in revealing what might be termed secondary effects, that was, effects which appeared in the later stages of cooling, such as α grains, pearlite, &c., whereas cupric reagents were very useful in dealing with primary structures which formed as the metal froze. He considered that metallographic work was sometimes published which would bear a different interpretation if cupric etching had also been used. In the present paper, however, he had been careful to state that the network structure could be revealed equally well when the samples were etched with the ordinary acid reagents ; in fact the greater part of the work was done with them, and it was only because of the difficulty of photographing a structure standing up in such strong relief that cupric etching was tried. He then found it to be extremely useful in detecting weak and diffusing structures. That both types of reagent revealed the same structure was surely clear from an examination of Figs. 1 and 2, representing the same area.

Dr. Hatfield had remarked on the inclusions seen in the networks of Figs. 1 and 6. As stated in the paper, those in Fig. 1 were due to the early stages of scale penetration at 1,050° C. In Fig. 6, the particles were chiefly scattered oxide inclusions usual in Armco iron and undetached pieces of scale. He (Mr. Whiteley) would point out that very few particles were to be seen in the networks of Figs. 4, 7, 9, 10 and 12. It was, in fact, quite easy to obtain the structure without them, even when examined under an oil-immersion lens. For that reason he could not agree with Dr. Hatfield's supposition that they prevented the copper deposition and so gave rise to the network appearance.

As regards Dr. Hatfield's remarks on the banded structure, it was no doubt true to say that no exact evidence had yet been produced to show that the bands were due to a differential distribution of oxygen. Probably the problem would not be finally disposed of until the bands could be separated and analysed. All he (Mr. Whiteley) had done was to point out four characteristics which were common to the banded and network structures. He was, at the same time, well aware that even more than that number would not be sufficient to establish identity. Similarities of this kind did, nevertheless, provide one with a working hypothesis.

It was particularly encouraging to find Dr. Desch's views so much in accord with the main conclusions reached in the paper. His suggestion that the problem should be studied by starting with the purest iron available and making additions to it was certainly a good one.

Replying to Professor Andrew, he (Mr. Whiteley) could not say why oxygen should penetrate along the grain boundaries.

It would appear as if this means of access was easier than direct penetration into the body of the grain. Whether a precipitation of oxide occurred at any temperature was also difficult to determine. He had stated in the paper that inclusions certainly appeared after a time in the α structure. The same thing happened in the γ structure at higher temperatures, but there the question was still more complicated owing to the greater probability of direct scale penetration. In answer to Professor Andrew's next question, he had found that, after a complete diffusion had occurred, a fresh structure could be formed when the specimen was re-scaled even in a closed tube, but would point out that the new grain boundaries were then for the most part in a different position. As regards the removal of the structure in polishing, he could assure Professor Andrew that, in the diffusion tests, the surface metal where the structure had existed had not been removed. In cases where the specimen was not prepared before the second treatment, he took care in polishing to leave a little scale on the surface so that the metal just beneath was exposed. Where the surface was first prepared, the second preparation was made on No. 000 emery paper only. Polishings on that paper could be repeated many times before the structure was erased. Professor Andrew's statement that sulphur was a deoxidiser seemed to require some qualification, for he (Mr. Whiteley) had given evidence which showed unmistakably that above 900° C. iron could reduce sulphur dioxide, and did so even in air.

He wished to express his obligations to Dr. Swinden for the interest he had shown in the work and for his confirmatory experiments. He (Mr. Whiteley) had no doubt that the structure was not in the scale but in the metal. It remained when the scale was completely detached and was certainly metallic in nature.

In reply to Dr. Northcott's question about the weights of the samples, he (Mr. Whiteley) had used small specimens purely as a matter of convenience. Much time was thereby saved in preparation. Most of the work had been done with pieces weighing between 0·5 and 1·0 grm. These suited the closed-tube experiments especially. As regards the piece 0·03 in. thick, this size had purposely been selected for deoxidation with hydrogen before scaling. He had found the structure on sections taken from quite large masses after they had been scaled, and was at a loss to understand why Dr. Northcott should think that mass had any bearing on the subject. As to the form in which the oxygen entered the iron, all he (Mr. Whiteley) could say was that ferrous oxide would not produce the effect. Dr. Northcott had criticised the experiment in which the oxidised specimen was heated for 44 hr. at 970° C. on the ground that diffusion at that temperature was slow. He (Mr. Whiteley) had, therefore, repeated the experi-

ment on the same sample at about 850° C., that was, at a temperature at which fairly rapid diffusion occurred. The specimen was heated for 1 hr. in a closed tube at 970° C. and after that for 48 hr. at 850° C. The tube was then opened and the heating continued for another hour at the latter temperature. A strong α-structure resulted, and he still thought it a fair inference to say that saturation of the iron with ferrous oxide did not prevent the formation of the network. With regard to veining, he had reasons for thinking that the network was connected with it, but could not at present be definite. No veining, however, was shown in Fig. 11, which was taken close to the fracture of a strip of Armco iron which had been broken just above 900° C. The piece had then cooled quickly through the Ar_3 point and rather small ferrite grains had formed. Dr. Northcott had suggested that specimens should be sectioned in a tapering manner after scaling. Here again there was no need to use a large piece for the purpose. As a matter of fact, a tapering effect could frequently be produced at more than one point on small pieces when scaled in air for an hour or more at 950° C. or above. The surfaces were then usually very uneven through irregular scale erosion. This occurred even when, as was usual, the surfaces had been ground before scaling, so that tapering areas could easily be observed. The effect obtained could be readily visualised from Figs. 2 and 12, and he had not considered it necessary to give an illustration. From the outside inwards the network lines diminished gradually in breadth and intensity until they finally vanished. In answer to Dr. Northcott's fourth point, he (Mr. Whiteley) had little doubt that sulphur would not produce the structure in the complete absence of oxygen from both the metal and the atmosphere ; at the same time the experiment might be worth doing.

Dr. Edwards had raised a question which he had considered frequently during the progress of the work. If the apparent diffusion of the structure was really due to the removal of its oxygen content by the carbon in the specimen, there appeared no reason why the rate of removal should change as it did on passing the Ac_3 point. Above 900° C. steel was decarburised readily in an oxidising atmosphere. Further, removal in this manner would not cause the broadening of the network lines seen in Figs. 6 and 10.

He agreed with Dr. McCance that a certain type of surface cracking appeared to be associated with scale penetration. The problem presented difficulties because, as a rule, subsequent hot-working destroyed the evidence. As to the action of sulphur, it was possible that intermediate quantities might be the most detrimental. Large amounts might cause more " wash," whereby penetration was counteracted to some extent. There was scope for a good deal of research on the effect of scaling at various

temperatures and in different atmospheres on the qualities of the surface finish, especially of rolled products.

He was greatly obliged to Messrs. de Belin and Richardson for the excellent photographs which they had contributed, and was pleased to note how well their observations agreed with his own. So far as his experience went, the structure given by electrolytic iron was weak compared with that given by Armco iron, for example, and it was these strong effects that were so difficult to photograph satisfactorily, since the different planes could not all be brought into focus on the plate together. Figs. A and B were certainly first-class at such high magnification. With regard to Fig. C, he had seen exactly the same effect at the surface of scaled silico-manganese steel, but the network was not there. When it was present, the particles in it were much finer, as far as he had observed, but he thought there could be little doubt that they consisted chiefly of silica.

NON-METALLIC INCLUSIONS IN FERRO-ALLOYS.[1]

By B. MATUSCHKA (Ternitz, Austria).

Summary.

After considering in general terms the structure and the physico-chemical behaviour of the slag inclusions in liquid and solid steel and their effect on the working and use of the finished material, the author deals with the degree of purity of the added ferro-alloys as an important quality factor in the production of high-grade alloy steels.

He then investigates the principal commercial alloys for their percentage of non-metallic inclusions, and discusses the nature, occurrence, and behaviour of these inclusions in steel melting.

Introduction.

The study of the non-metallic inclusions in iron and steel has engaged the attention of steel manufacturers and users for many years, and several suggestions have been made for assessing the quality of steel in terms of the quantity and form of the inclusions contained in it. Some of these suggestions have even been included in acceptance specifications. More recent knowledge of the subject, however, tends to show that the non-metallic inclusions certainly have an important bearing on the quality of steel, but that, in terms of the form of the inclusions and numbers in which they occur, it is impossible to assess even approximately their influence on the properties of steel. In their valuable work on the inclusions in steel, A. M. Portevin and R. Perrin have clearly demonstrated that it is not enough merely to regard the inclusions as non-metallic particles admixed with steel, which, since they behave differently from steel, destroy the continuity of the metal and set up changes in stress. The inclusions are actually complex, microscopic particles of slag which, like the slag that covers the bath in the furnace, are continually setting up mutual chemical actions with the adjoining metal. This means that the structure of the slag inclusions distributed in steel is equally as important as, if not more important than, their form and distribution. While these latter factors are frequently governed by the conditions of casting and cooling, the physico-chemical structure of the inclusions is largely determined by the metallurgical processes which take place when the steel is being melted. In this connection, the factors

[1] Received February 12, 1935.

which are usually stated to have a decisive effect on the quality of the steel must be very pronounced in their action. The variations in the steel bath in terms of time will have their repercussions on the structure of the slag inclusions, whereas the structure will not be further affected to any considerable extent by the processes set up just before the charge is cast, as the time will probably be too short. The inclusions will therefore be profoundly affected by the way the steel is refined and the time taken to refine it, and the quality of the steel will be favourably affected by all measures taken to curtail the duration of the metallurgical processes or to speed them up.

In his research, Portevin refers *inter alia* to the important influence of the added alloys. The present paper deals with the nature and quantity of the non-metallic inclusions in ferro-alloys—a problem of growing importance in view of the steadily increasing use of alloyed and super-alloyed steels. It also affords some guide to the nature of the inclusions which can form anew, under similar conditions, in the alloyed steels. The present investigation is confined to the effect of metals as alloying elements, but not as deoxidising agents.

Classification.

The chief alloys used in the production of alloy steels are as follows :

(1) Tungsten alloys, for the manufacture of high-speed steels, steels for hot-working, magnet steels, high-endurance steels, tool steels and hack-saw sheets, &c.

(2) Chromium alloys, for the production of heat- and acid-resisting steels, rustless plates, cutting steels, chromium magnet steels, drawing dies, cutlery steels, &c.

(3) Nickel metal, for nickel alloys, highly heat-resisting alloys and acid-proof steels, valve steels, nickel-chromium structural steels, &c.

(4) Molybdenum alloys, as an addition to high-speed steels, acid-proof and structural steels, and also for chromium-molybdenum steel.

(5) Cobalt metal, mainly for the production of cobalt high-speed steels and cobalt magnet steels.

(6) Vanadium alloys, as an addition to a wide variety of steels in small and large quantities, particularly vanadium high-speed steels, steels for hot-working and tool steels.

(7) Manganese alloys, used in the manufacture of manganese steel for wear-resisting parts, spring steels and tools which are mass-stable ; also, more recently, for rustless manganese-chromium alloys.

(8) Silicon alloys, for transformer or dynamo sheets, spring steel, alloy steel castings, &c.

(9) Aluminium metal, for heat-resisting chromium-aluminium alloys, non-magnetic alloy; and, more recently, for nickel-aluminium magnets.

(10) Copper, as an addition to acid- and weather-resisting steels.

General Considerations.

Consideration of the grades of steel most frequently used at the present time shows that the quality of alloyed metals varies within extremely wide limits, and this means that the requirements of the alloys as regards purity must also differ. In theory, the added alloy must be higher in quality, (1) the greater the amount of it that is added, (2) the later the point of time at which the addition is made, (3) the more difficult it is to reduce the inclusions in the alloy, and (4) the higher the requirements of the steel as regards quality in service.

Two types of slag inclusions are differentiated, according to their size, whether macroscopic or microscopic. In the alloy, less importance will be attached to the coarse macroscopically admixed slags, provided their quantity is kept within limits and slag streaks are not present.

Microscopic slags occur either in the form of small bubbles (vesicles) or crystals.

The globular inclusions distributed throughout the cross-section are seldom uniform in size. Examined under a high-powered microscope, they will usually be found to be surrounded by numerous fine slag vesicles, which remain in suspension in the liquid metal, probably in the colloidal condition. It is often possible to observe inside them metallic segregations, which have probably originated from emulsions during the process of reduction, or are caused by the ability of the slag, in the liquid state, to dissolve metal which has segregated when it solidified.

The irregular crystalline inclusions are seldom present in larger forms. They are mostly small and of uniform size, and are generally surrounded by dense, slag-free metal. In the probable absence of any colloidal cohesion, they segregate more rapidly without coalescing, in spite of their smaller dimensions. Groups of angular inclusions are frequently found which have solidified on their way to the surface. The photomicrograph of an alloy containing crystalline inclusions gives the impression of greater purity and chemical stability.

The slag inclusions which remain behind in steel undergo certain modifications by the hot- and cold-working to which the metal is subjected. Ductile slags are stretched together with the steel when the latter is worked, without acting detrimentally as foreign bodies, provided that their melting point is not too low and that they are chemically inert to their surroundings.

If microscopically small and not very hard, they are not very dangerous in the finished tool.

Brittle slag particles, if of larger dimensions, can set up cracks when the metal is hot-rolled or forged. They are only partially able to follow the stretching of the steel, and in doing so they break into several parts, between which there are cavities which are more or less filled up with the plastic steel. Very small slag crystals participate only indirectly in the stretching process, being displaced like a floating body by the flowing metal, and so being harmless when the metal is hot-worked. When steel is cold-worked or hardened, or the tool is doing its work, all slag inclusions will be detrimental which are of definite size or are concentrated locally in fairly large groups, and this remark applies particularly to the inclusions possessing a considerable degree of mechanical hardness. Small, soft inclusions, on the other hand, will constitute less harmful foreign bodies. The conditions are analogous as regards surface stresses, wear, and ability to take a good finish.

It is not possible to ascribe definite phenomena or material defects *a priori* to the effect of slag inclusions, because, under the same conditions of manufacture, other irregularities may incidentally occur in the steel. Each particular case must be specifically examined and assessed accordingly. Among the defects which may frequently be ascribed to slag inclusions are blisters, cracks, fissures and similar blemishes or defects in soft alloyed and unalloyed steels, and, in the case of hard steels, cracks and flaws which develop while the steel is being hardened or is in service.

For purposes in which the steel will be sensitive to these effects, it is advisable to use alloys which are as free from slags as possible.

Alloys.

The degree of purity of the commercial ferro-alloys will now be considered briefly.

1.—*Tungsten Alloys.*

The high melting point of tungsten, 3,300° C., makes it impossible to produce tungsten in the liquid state. The standard ferro-tungsten, produced in ingot form in the pasty state, often contains a fair amount of slag, as shown in Fig. 1 (Plate XIII.), the metal being interspersed by coarse and fine vesicular silicate slag particles, especially where the carbon content is low. Low-carbon ferro-tungsten produced by the thermit process also frequently contains numerous vesicular inclusions, since the metal is only liquid for a short time, and this is not long enough for the large quantity of fine slag particles which occur to segregate

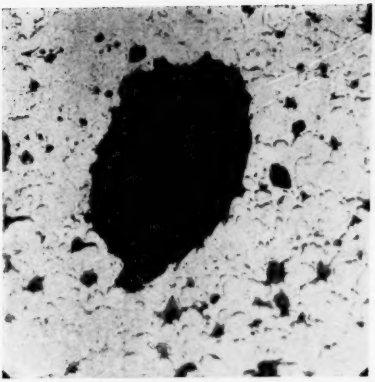

FIG. 1.—Slag Inclusions in Ferro-Tungsten. × 500.

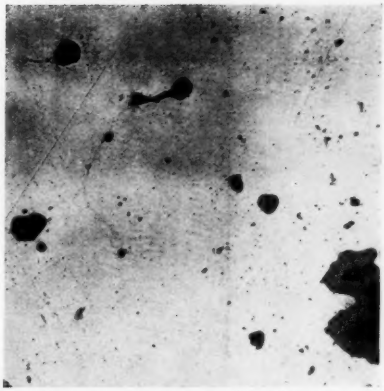

FIG. 2.—Inclusions in Ferro-Chromium. × 100.

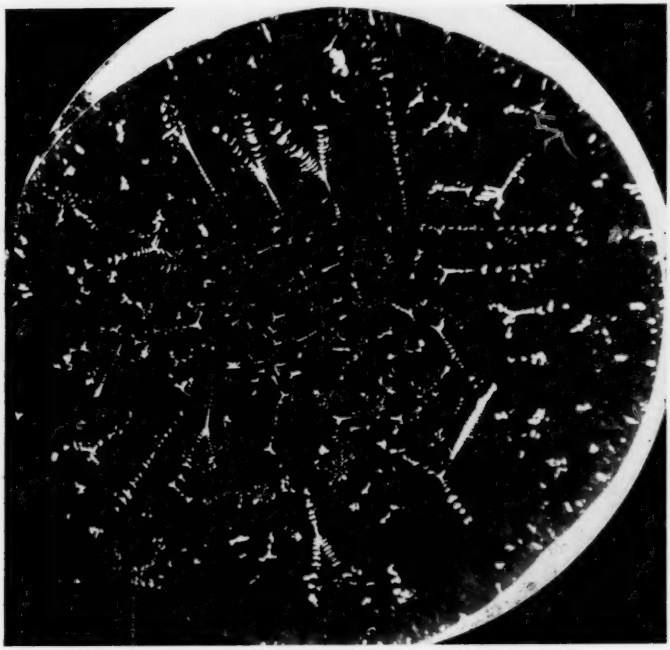

FIG. 3.—Metallic Dendrites in Slag Inclusion in Ferro-Chromium. × 500.
(Fig. 1 reduced to three-quarters linear in reproduction.)

[*Matuschka.*

[*To face p.* 216.

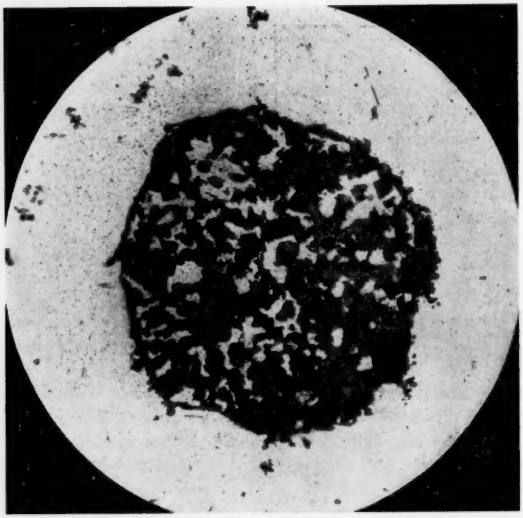

FIG. 4.—Slag Particle in Ferro-Chromium, depicting slag-metal emulsion. × 100.

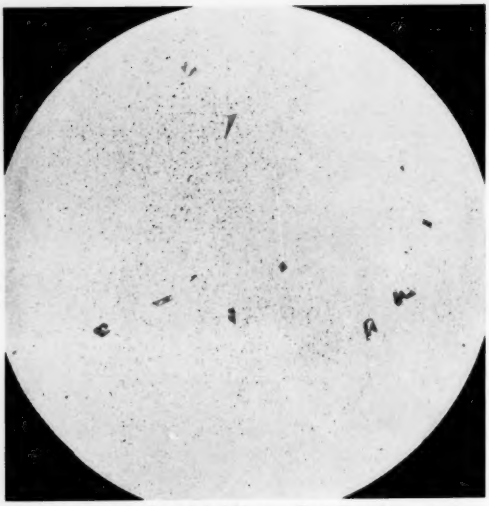

FIG. 5.—Chromite Crystals in fairly pure Ferro-Chromium. × 100.
(Micrographs reduced to three-quarters linear in reproduction.)

[*Matuschka.*

FIG. 6.—Chromite Crystals in Ferro-Chromium. × 500.

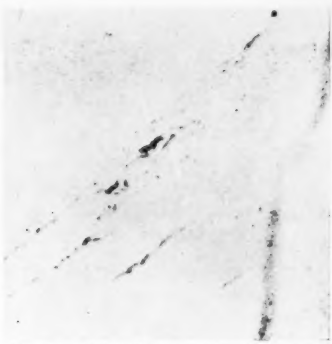

FIG. 7.—Mond Nickel, very free from slag. × 500.

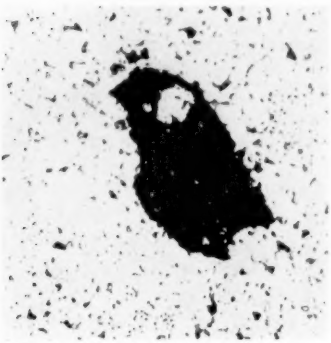

FIG. 8.—Cube Nickel; slag inclusions. × 500.

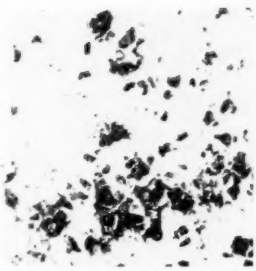

FIG. 9.—Slag Particles in Ferro-Molybdenum. × 100.

FIG. 10.—Globular Inclusion in Ferro-Molybdenum. × 500.

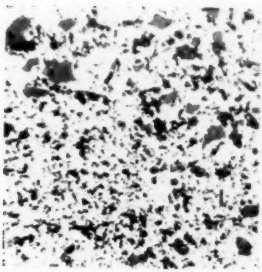

FIG. 11.—Sintered Molybdenum. × 100.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Matuschka.*

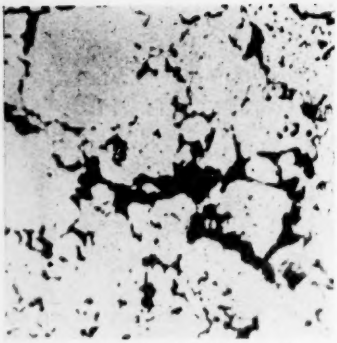

FIG. 12.—Inclusions in Cobalt. × 500.

FIG. 13.—Inclusions in Ferro-Vanadium. × 500.

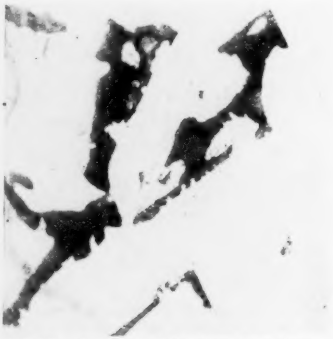

FIG. 14.—Vanadium Oxide in Ferro-Vanadium. × 500.

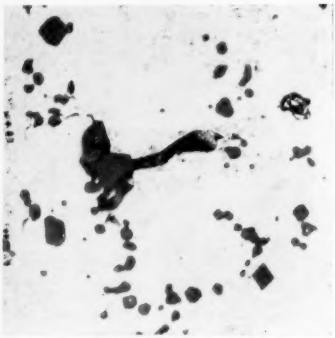

FIG. 15.—Manganese Silicate Particles in Ferro-Manganese. × 500.

FIG. 16.—Slag in High-Silicon Ferro-Silicon. × 500.

FIG. 17.—Oxide Particles in Electrolytic Copper. × 500.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Matuschka.*

[*To face p.* 217.

out. Tungsten metal produced chemically is free from slag, and in other respects also constitutes a very pure alloy.

2.—*Chromium Alloys.*

Although chromium has a melting point of only 1,520° C. approx. and can therefore be produced in the liquid state, the degree of purity of the ferro-chromium alloys varies considerably. The reason for this is the high viscosity of the metal above the melting point. The low-carbon grades, in particular, often contain numerous vesicular inclusions (*see* Fig. 2). The metallic surface between the bubbles interspersed by very fine inclusions should be noted. Isolated inclusions in this ferro-chromium exhibit metallic segregations of dendritic structure as in Fig. 3, or an emulsion between the metal and slag depicted in Fig. 4 (Plate XIV.). Generally speaking, these inclusions are chromite/chromic-oxide crystals in a eutectic and partially siliceous ground-mass. The pure low-slag ferro-chromium contains, exclusively, small, angular, chromite crystals of a uniform light-grey colour (*see* Fig. 5). These inclusions appear to be softer, the lighter they are in colour. In very soft grades of ferro-chromium there are also slightly larger chromite crystals of the type and orientation shown in Fig. 6 (Plate XV.). The silicon content of these pure grades of ferro-chromium is usually very low. At the present time, chromium alloys of a high degree of purity are being marketed.

3.—*Nickel.*

Nickel metal produced chemically varies considerably in purity according to the process of manufacture adopted. Mond nickel (illustrated in Fig. 7) is the purest and has a fine external appearance as well. The microsection of Mond nickel is perfectly free from slag, except for a few circular zones on the outside of the nickel balls at which fine NiO-slag particles have accumulated. Mond nickel is therefore very suitable for incorporating in furnace charges. The microsection of cube nickel, as depicted in Fig. 8, is much less pure. Besides containing various fairly large inclusions, the entire cross-section is interspersed by numerous very fine oxide slag particles. These are probably unreduced residues of nickel oxide from the reduction of the nickel oxide cubes mixed with flour. The photomicrograph explains why, when cube nickel is used for high-nickel steel alloys, an initial ferro-nickel alloy is often made beforehand.

The American cathode-nickel recently marketed in Europe is also a very pure material for furnace charges. It contains only isolated traces of small nickel oxide inclusions. The anode plates frequently marketed are very impure and interspersed by numerous fine and extra-fine slag suspensions.

When nickel is being melted in the steel bath, it must be remembered that nickel is a nobler metal than iron and that, therefore, the oxides incorporated in the steel bath with impure nickel immediately react with the iron, and not only greater nickel losses, but also an undesirable oxidation of the bath may be expected.

4.—*Molybdenum Alloys.*

Molybdenum resembles tungsten in its high melting point of approx. 2,600° C. In the case of alloys of higher molybdenum contents, it is usually manufactured electro-thermally in ingots. Ferro-molybdenum produced in this way frequently contains fairly large quantities of oxide slag inclusions, as illustrated in Fig. 9. Ferro-molybdenum can also be produced by the silico-thermal process. Ferro-molybdenum obtained in this way usually contains spheroidal silicate inclusions (Fig. 10). Molybdenum alloys of this kind and possessing a high degree of purity are now being marketed, and they contain only isolated inclusions. Silico-thermal ferro-molybdenum has also a low carbon content, and is therefore very suitable for use in the steel furnace.

Molybdenum for commercial purposes is also manufactured chemically. Being very volatile in powder form, this molybdenum metal is not very suitable for steel manufacture. It is also made into briquettes with the addition of a binding medium. As the binder is usually silica, this sintered molybdenum metal always contains fairly large quantities of silicate and inclusions of quartz, which are incorporated in the steel bath with the specifically heavier metal (Fig. 11). This fact should be particularly noted, especially where the additions are made later on in the melting process.

5.—*Cobalt.*

Like nickel, this important and expensive metal is produced chemically. Sometimes the two oxides are concentrated in the same " heat " or stage, and afterwards separated. The oxide of cobalt is reduced in a similar way to cube nickel, by mixing with flour and heating the moulded cakes in the crucible. With cobalt, too, this process yields an impure metal interspersed with numerous fine and coarse unreduced cobalt oxide slag particles (*see* Fig. 12, Plate XVI.). It is at present impossible to obtain a purer metal commercially. In view of the extremely high demands made of cobalt steels, it would be desirable if the quality of cobalt metal could be improved, besides which the big variations in the metal loss and analysis figures which occur when high-cobalt steels are melted would be minimised.

6.—*Vanadium Alloys.*

The commercial alloys containing approx. 50 per cent. and

80 per cent. of vanadium have melting points of 1,500° and 1,700° C., respectively, which means that both of them can be produced electro-thermally in the liquid state. The 50 per cent. ferro-vanadium is fairly pure. The inclusions which occur are very small (*see* Fig. 13). At the present time 50 per cent. ferro-vanadium is marketed which is very free from slag. The 80 per cent. ferro-vanadium is much less pure, because there seem to be difficulties in separating the slags at the higher melting point. An entire network of unreduced vanadium oxide will be noted in the photomicrograph of the 80 per cent. ferro-vanadium (Fig. 14). As ferro-vanadium has a low specific gravity and easily oxidises, it is preferable to use the purer 50 per cent. alloy for steel manufacture.

7.—*Manganese Alloys.*

Of the ordinary manganese alloys, high-carbon ferro-manganese and spiegeleisen are very free from slag when examined under the microscope. At higher powers, isolated grey oxy-sulphides are noticed—in blast-furnace ferro-manganese more than in the electric furnace product. Differences have also been noted in the oxygen content, but there is no definite indication of these in the photomicrograph.

In the refined grades containing less carbon, which are already partially reduced with silicon, a number of spheroidal dark-grey manganese silicate particles occur, these being more frequent and in fairly large groups in the softer grades containing 0·1 to 1·0 per cent. of carbon (depicted in Fig. 15). In these grades also were noticed very fine specks of bluish sheen, possibly arising from segregations of manganic oxide. In the carbon-free commercial manganese metal, it was possible to detect only these fine specks, but they occurred in greater numbers. Despite their low carbon content, the commercial manganese-silicon alloys usually have very few inclusions in them. This is probably due to the manganese silicates being separated more easily—a fact which explains why these alloys have been widely adopted for steel manufacture.

8.—*Silicon Alloys.*

When fairly large quantities of silicon are added to steel as an alloying element, it is essential that it be as free as possible from slag, and the ordinary 45 and 75 per cent. ferro-silicon alloys usually satisfy this requirement very well. Freedom from slag in the steel depends mainly on the external condition of the alloy, the size of the pieces, their porosity and moisture, the method of making the addition, and the state of the metal bath at the time the silicon is added. Dark grey silicate slags in the form of streaks are often found in the high-silicon alloys.

Larger quantities of such slags usually only occur with 90 per cent. ferro-silicons (*see* Fig. 16), because, owing to their high melting point, they cannot be manufactured without a certain amount of trouble. The silicate slags also exhibit light-grey, unreduced quartz grains. When these high-silicon alloys are properly melted, they yield compact lumps of a bright grey appearance.

9.—*Aluminium.*

Since aluminium is produced electrolytically, it has a high degree of purity. There is the risk of its absorbing gases when it is being remelted and cast into the bars of commerce. Aluminium containing gas gives bars with pipes or shrinkage cavities which penetrate to a surprising depth. The occluded gases naturally find their way directly into the liquid steel with the alloy. Aluminium being at the same time a powerful deoxidiser, attention should be paid to the way in which it is added and to the state of the metal bath (as in dealing with silicon), if slagging and losses are to be obviated.

10.—*Copper.*

As an alloying element copper is used primarily as an addition element for non-corroding (rustless) steels, for which reason the added copper should be as pure as possible. Even electrolytic copper exhibits fine, round, blue cuprous oxide inclusions under the microscope at suitable magnifications (Fig. 17). Especially where the added percentages are high should particular attention be paid to the purity of the copper. Like nickel, copper is more noble than iron, so that impure copper gives up its oxygen to the iron and oxidises the steel.

CORRESPONDENCE.

Professor A. M. PORTEVIN (Paris) wrote that he had pursued, in conjunction with Mr. René Castro at the Laboratory of the Ugine Steelworks, a general study of the inclusions existing in industrial plain and special steels; the first part (relating to ordinary steels) of a memoir on "the Morphology of Inclusions" was finished and would be presented, in the near future, to the Iron and Steel Institute; it would be followed by a second part on special steels now in course of preparation. Professor Portevin and his colleague had been very interested in the work of Dr. Matuschka, and offered him their congratulations.

Having himself studied the alloys of chromium and particularly the ferro-chromiums from the point of view of the inclusions in them, he desired to make a few remarks regarding the present paper as well as that published recently by Dr. Matuschka in *Stahl und Eisen* (1934, vol. 54, p. 845).

Regarding the inclusions of chromite which the writer thought he was the first to announce under this name (Portevin and Perrin, *Journal of the Iron and Steel Institute*, 1933, No. I, p. 169), it had been possible to determine exactly their composition by the analysis of the residues (chlorine method) in a low-carbon, low-chromium steel, free from insoluble carbides and containing exclusively this type of inclusion as shown by microscopical examination. The ratio of the oxygen in the Cr_2O_3 to that in the FeO was found to be approximately 3, corresponding, therefore, to the formula $Cr_2O_3.FeO$. Needless to say, the total oxygen of the residues was equal to the total oxygen found by the method of reduction by carbon *in vacuo* at 1,720° C.

In his first article Dr. Matuschka had stated that it was not possible to find chromium silicates in the ferro-chromiums on account of the non-miscibility of silica and chromium oxide due to the acid character of the latter. Nevertheless, he stated that the ground-mass of the inclusion represented in Fig. 4 of that paper was "partly siliceous." Professor Portevin thought that that really was a case of chromium silicates, and had mentioned it in an article entitled "Inclusions within Inclusions" in *Metal Progress* (1934, Jan., p. 42), in which was given a micrograph altogether similar to Fig. 3 in the author's article, and another micrograph of the same area under dark-field illumination which showed the very clearly crystalline structure of the silicate, generally accompanied either by metallic dendrites or by perfectly defined cubic metallic crystals. (Reference might equally be made to Figs. 2, 5, 6, 17, 18, 19 and 20, which he, Professor Portevin, had published in *Technique Moderne*, May 15, 1934.) Those

inclusions, which might be met with both in certain ferro-chromiums with relatively high silicon contents (1 to 1·5 per cent.) and also in soft steels with 30 per cent. of chromium (0·5 per cent. of silicon), had been analysed approximately in a piece from the feeding head from such a steel which contained large quantities. Solution of that metal in dilute hydrochloric acid left an abundant residue of a green colour, containing 40–50 per cent. of SiO_2, 22–20 per cent. of Cr_2O_3 and 6 per cent. of FeO, the remainder consisting of Al_2O_3 and a little MnO ; that analysis was only approximate, because the metal contained a small quantity of carbides which had to be separated with the oxides, but it showed the clearly siliceous character of those inclusions. Some SiO_2–Cr_2O_3–FeO slags, prepared over a bath of molten soft ferro-chromium in a high-frequency furnace, had structures entirely analogous for silica contents of about 50 per cent. and variable relative contents of Cr_2O_3 and FeO. The colours of these slags (visible by polarised light or under dark-field illumination) were green for the chromium-rich slags and orange to brown for those rich in iron. Further, it frequently happened that silicates of two different colours were found in close proximity in the same sample of ferro-chromium.

By reflected light those silicates might have an appearance resembling that of the more or less globular inclusions of chromium oxide met with in certain ferro-chromiums, such as, for example, thermite metallic chromium, but they were distinguished by the fact that they were completely opaque to polarised light or under conical illumination.

Dr. Matuschka thought also that chromium sulphide, being very easily decomposed by heat, could not exist as inclusions in ferro-chromiums. Professor Portevin, on the contrary, thought that sulphur produced non-metallic compounds with chromium with great facility, particularly in the presence of oxygen. If such sulphides were observed only infrequently, that was due to the fact that the commercial ferro-chromiums made nowadays were fairly low in sulphur, and that for the contents usually met with (0·005 to 0·015 per cent.) that sulphur was probably almost entirely soluble in the metal in the solid state. In any case, as soon as the sulphur content of the metal exceeded 0·03–0·04 per cent. numerous pale-rose globules of sulphide of chromium (and of iron) were observed under the microscope. The structure of those sulphides was rarely simple ; generally it consisted of a very fine eutectic of metal and sulphide which was difficult to resolve owing to the pale colour of the mass. The triple eutectic chromite-sulphide-metal could also be observed, and an example was furnished by the micrograph Fig. 15 on Plate XII. of the article by Portevin and Perrin mentioned above. It was very probable that that constituent was an oxysulphide ; in fact, a

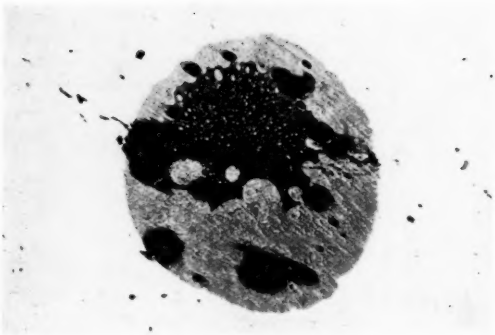

FIG. A. × 65.

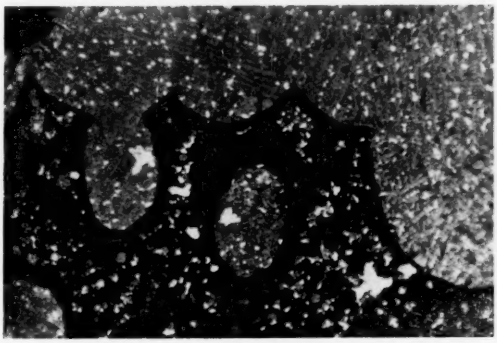

FIG. B. × 1,100.

FIGS. A and B.—Oxysulphide Inclusion in a Cast of Ferro-Chromium. Unetched.

(See Portevin's correspondence.)

[*Matuschka, correspondence.*

[*To face p.* 222.

soft ferro-chromium (carbon 0·05 per cent.), containing 0·15 per cent. of oxygen and chromite inclusions only, after remelting with a certain quantity of FeS, presented, for a practically unaltered oxygen content and a sulphur content of 0·117 per cent., solely inclusions of this rose-coloured constituent to the exclusion of all other oxides. The examination of a similar cast revealed a large inclusion, the structure of which was illustrated in Figs. A and B (Plate XVIA.) at different magnifications. The peripheral constituent—probably separated in the liquid state, as was suggested by the very characteristic form of the droplets—was this oxysulphide, which had crystallised later, expelling metal and eutectic oxide. The dark-coloured constituent was either chromium oxide or else a silicate very rich in chromium oxide; its transparency to polarised light was, in fact, very low. There appeared to be also a precipitation of metallic particles having the appearance of a eutectic.

AUTHOR'S REPLY.

Dr. MATUSCHKA replied to Professor Portevin that the data regarding the ferro-chromium alloys and the slag inclusions occurring in them had been taken from a research which he had undertaken in 1931, and had presented before the Montanistische Hochschule in Leoben in December, 1932. The primary cause which had led to the investigation of the degree of cleanliness of ferro-chromium alloys had been a delivery of very dirty ferro-chromium which had given rise to considerable troubles in the production of rustless iron. The paper was presented again in similar form on March 16, 1934, before the Sub-Committee for Electric Steel Operation in Düsseldorf, and was published in August of the same year.

The author had read with great interest in the *Journal of the Iron and Steel Institute* (1933, vol. I. p. 189) that Professor Portevin and Mr. Perrin had come to precisely the same conclusions in their investigation, in particular, that they had succeeded in obtaining proof that the crystalline inclusions in ferro-chromium, as the author had assumed, consisted of pure chromite.

On the basis of data contained in the literature, particularly the later investigations of H. Salmang and S. Kaltenbach,[1] and also of P. P. Budnikoff and E. L. Mangelgrün,[2] it could be taken as established that chromium oxide and silica did not form a chemical compound, and therefore pure chromium-silicate inclusions could not occur in ferro-chromium. In agreement with the data of Professor Portevin, the author had, never-

[1] *Feuerfest*, 1931, vol. 7, p. 167.
[2] *Bericht der deutschen keramischen Gesellschaft*, 1932, vol. 13, p. 524.

theless, found later that the chromium-bearing iron silicates known to exist in chromium steels could also occur in ferro-chromium, and that the ground-mass of the inclusions did not consist solely of a binary chromite/chromium-oxide eutectic but of a ternary chromite/chromium-oxide/chromium-iron-silicate eutectic. The iron silicate could replace various proportions of ferrous oxide by chromium oxide, and in that way were formed the variously coloured slags which Professor Portevin had observed.

With regard to the pale-rose coloured inclusions which Professor Portevin had observed in ferro-chromiums containing higher proportions of sulphur, the author was of opinion, nevertheless, that these could not consist of chromium sulphide. According to H. Löfquist,[1] the colour of chromium sulphide was light-grey to grey. It appeared much more probable that the rose-coloured inclusions consisted of ferrous sulphide, which could contain chromium in solution, the colour then being somewhat altered, or of a chromium-iron double sulphide, which was stable at high temperatures. Chromium sulphide should, for example, occur in rustless free-cutting steels, which were intentionally produced with higher sulphur contents; nevertheless, it was known that other substances, such as zirconium or molybdenum, must be added to them to stabilise the sulphur, in order to produce inclusions, which broke up the turnings in the same way as in the ordinary free-cutting steels.

[1] *Jernkontorets Annaler*, 1933, vol. 117, p. 49.

TRANSFORMATIONS IN IRON-ALUMINIUM ALLOYS.*

By C. SYKES, M.Sc., Ph.D., F.Inst.P., and H. EVANS, Assoc., Met. (Manchester).

Summary.

Under conditions of slow cooling, atomic rearrangement ("ordering") occurs in alloys of the approximate composition Fe_3Al. Its effect on the cooling curve, electrical resistance and magnetic properties of this series of alloys has been examined. The heat evolution due to the ordering process starts at about 560° C., and continues over a considerable range of temperature, probably down to about 200°–250° C., depending on the cooling rate. Measurement of the resistivity of samples quenched from various temperatures also enables the critical temperature to be ascertained, and the value so determined is in good agreement with that obtained by purely thermal methods.

The magnetic change points of alloys containing from 11 to 17 per cent. of aluminium by weight ($Fe_3Al = 13{\cdot}9$ per cent. Al) have been determined. It appears that the ordering process can in certain cases affect the magnetisation-temperature curve, so that the magnetic properties are of considerable interest from the academic point of view.

This paper describes an investigation of interesting transformations occurring in the solid state in alloys of iron containing from 11 to 17 per cent of aluminium by weight.

The thermal equilibrium diagram of the whole range of aluminium-iron alloys has formed the subject of several previous investigations. Ageew and Vheer[1] published a diagram which incorporates the results of Gwyer,[2] of Kurnakow, Urazov and Grigoriev,[3] of Isawa and Murakami,[4] and of Gwyer and Phillips.[5] It indicates that the solubility of aluminium in solid iron varies from about 30 per cent. by weight at room temperature to 35 per cent. at 1,100° C. Isawa and Murakami,[4] and more recently Körber,[6] have shown that the system exhibits the phenomenon of a closed γ loop, *i.e.*, beyond 1·2 per cent. aluminium the γ solid solution persists from room temperature to the solidus. Whilst this conclusion does not agree with the original diagrams of Gwyer,[2] and of Kurnakow,[3] there can be little doubt that the closed γ loop does exist; consequently the alloys considered in this paper are single-phase alloys, having body-centred cubic structures, at all temperatures in the solid state.

* Received February 4, 1935.

Isawa and Murakami[4] have determined the effect of aluminium on the magnetic change point in iron ; the following account of their results is taken from an abstract :[7] "The A_2 point decreases gradually at first and then rapidly as the aluminium is increased, and the point reaches room temperature at 16·5 per cent. aluminium."

Recently it has been shown,[8,9] that the electrical resistance and lattice structure of a restricted range of these alloys can be modified by heat treatment. The range of composition showing this type of effect stretches from about 12 per cent. to 20 per cent. aluminium by weight and includes the composition Fe_3Al (13·9 per cent. of aluminium by weight) where the effects are a maximum. Bradley and Jay[9] have examined the lattice structure of alloys in both the rapidly-cooled (quenched) and slowly-cooled conditions. As a result of the experimental method employed they were able to determine the precise arrangement of the aluminium atoms in the iron lattice. Their results will be discussed in greater detail later in this paper ; for the present it is sufficient to state that they found that changes in distribution of the aluminium atoms were produced by heat treatment. For example, in an alloy of the composition Fe_3Al examined as quenched, the aluminium atoms were arranged at random in the body-centred iron lattice. In the same alloy examined in the slowly-cooled condition over 90 per cent. of the aluminium atoms were found in one particular type of position in the iron lattice, which was still body-centred. The changes in atomic structure brought about by heat treatment are accompanied by changes in electrical resistance, the rapidly-cooled alloys having an appreciably higher resistance than slowly-cooled alloys.

The change from the disordered state to the ordered state under conditions of slow cooling takes place in several non-ferrous alloys, such as Cu_3Au, Cu_3Pd, &c. ; the present case is of more than usual interest, as one of the constituents is ferromagnetic.

Since the ordered state is the stable one at low temperatures, it must correspond to a lower state of potential energy, and consequently an evolution of heat is to be expected, due to the rearrangement process. A theoretical investigation of the phenomenon has been made by Bragg and Williams.[10] They calculated, on the basis of certain assumptions, the change in the degree of order with temperature for an alloy in equilibrium, and from this they determined the contribution made by the ordering process to the heat content of the alloy. Certain marked differences[11] exist between a transformation of this type and an ordinary phase change. In the latter case, under conditions of slow cooling, the specific heat becomes infinite at the temperature of the phase change, and cooling of the alloy only proceeds

when all the latent heat has been evolved. In a transformation of the Bragg-Williams type, the commencement of the ordering process merely produces an increase in specific heat,* which then gradually decreases as the temperature decreases—that is, the alloy never stops cooling. Perfect order is theoretically possible only at absolute zero temperature, so that in practice the transformation contributes to the specific heat until the rate of cooling and temperature are such that no diffusion of atoms can take place. No heat evolution which could be associated with the atomic rearrangement process had ever been reported in aluminium-iron alloys. Theoretically, the effect expected is quite small, about half the magnitude of the heat evolution in the β brass transformation, and this may have been missed by previous investigators. It seemed desirable, therefore, to re-examine the alloy system and determine whether or not the predicted thermal arrests occurred. During the course of the investigation it was found that the results were complicated by the ordinary magnetic changes in the alloys, and it became necessary to repeat the work of Isawa and Murakami. Consequently the paper records not only transformations due to order-disorder changes, but also the magnetic change points of these alloys.

Preparation of the Alloys.

The alloys were prepared from Swedish iron and a specially pure form of aluminium, containing 99·97 per cent. of aluminium. The raw materials were melted in quantities of from 10 to 20 lb. in a high-frequency furnace *in vacuo*. When the alloy was molten the gas pressure in the furnace as measured by a Pirani gauge was less than 5×10^{-3} mm. The molten charge was cast *in vacuo* into a water-cooled mould. The ingots so produced were soaked for 6 hr. at 1,200° C., swaged to $1\frac{3}{4}$-in. rounds and again soaked for 6 hr.

The charges were melted in fire-clay crucibles, and a certain amount of trouble was experienced in the initial stages due to silicon "pick-up," probably produced by reduction of the lining material by the aluminium. The authors attempted to eliminate this difficulty by lining the crucibles with a layer of very finely divided alumina applied as a paste and then baking the crucibles before use. This produced a considerable improvement but the silicon content of the ingots still varied slightly.

The analyses of the ingots used are given in Table I.

Specimens.—The samples used for cooling-curve experiments were in the form of short tubes, $1\frac{3}{8}$ in. in outside diam., $\frac{3}{4}$ in. in internal diam., and $1\frac{5}{8}$ in. long, whilst the specimens for magnetic tests were rods 0·25 in. in diam. and 5 in. long. These latter

* Theoretically 25 per cent. for the alloy Fe_3Al.

specimens were swaged from $1\frac{3}{4}$-in. bar and machined to finished size.

Homogeneity.—The great difference in density between aluminium and iron can be expected to give rise to segregation in alloys of these two metals. The authors tried to eliminate this as far as possible in manufacture. The ingots were poured with full high-frequency current input into the furnace coil, consequently the molten metal was thoroughly mixed at the commencement of pouring. The metal solidified rapidly in the water-cooled mould, so that segregation in the ingot mould must have been small. Finally, the prolonged soaking treatment should have helped in removing any small inhomogeneity. The resulting uniformity can be judged from the following result: The electrical resistivity of each of the nine magnetic test-pieces of

TABLE I.—*Analyses of the Ingots Used.*

No.	Al. %	Si. %	C. %
1	15·4	0·03	0·02
2	17·0	0·07	0·02
3	13·4	0·10	0·02
5	13·8	0·03	0·02
6	14·1	0·02	0·02
7	13·9	0·02	0·02
9	7·8	0·08	0·02
12	11·2	0·03	0·02
13	11·9	0·09	0·02

ingot No. 1 was found to be the same to within 1 per cent. This variation is of the same order as the experimental error of measurement, but if it be assumed that it is entirely due to variation in composition it corresponds to a maximum difference in mean composition of 0·05 per cent. of aluminium. It seems reasonable to conclude, therefore, that the various samples from one ingot were practically identical in composition. This point has been rather elaborated, because later the behaviour of different samples from the same ingot will be compared, and where physical properties change rapidly with composition it is advisable to be certain of freedom from segregation.

Various tests were carried out to determine the absolute accuracy of the analytical method used to obtain the aluminium content. A known mixture of aluminium and iron was prepared, and eight analyses taken; the mean error in the aluminium content was 0·8 per cent., *i.e.*, 0·11 per cent. of aluminium on a 14 per cent. alloy, and the maximum error was 1·4 per cent. Duplicate analyses on the specimens agreed to within 0·1 per

cent. of aluminium, so that the authors feel justified in assuming that the aluminium contents as given in Table I. are accurate to within 0·15 per cent. of aluminium; it is highly probable that the error is on the high side, *i.e.*, the true aluminium content is about 0·07 per cent. lower than that given in Table I. That the samples Nos. 5, 6 and 7 are correctly placed as regards aluminium content is supported by the electrical measurements—alloy No. 7 gives the lowest electrical resistivity of the three alloys. As a further test, density measurements were made on the alloys and the compositions checked from a curve previously published,[12] which was obtained on a different series of specimens analysed by another analyst. The agreement with the results shown in Table I. is very satisfactory.

It is concluded therefore that the specimens made for this investigation are homogeneous and correctly analysed to within 0·15 per cent. of aluminium.

Cooling Curve Experiments.

It has already been mentioned that the heat evolution to be expected from an order-disorder transformation is very small compared with that available in a phase change. One of the authors[11] has described a modified cooling-curve method which is specially suited to this type of problem. This will be briefly described with the help of a diagram of the apparatus (*see* Fig. 1).

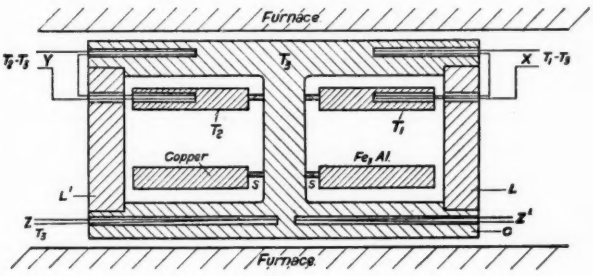

FIG. 1.

C is a cylindrical piece of copper containing two cylindrical cavities; in one is placed the cooling-curve specimen, an iron-aluminium alloy, and in the other a copper specimen of identical size. Both specimens are mounted on heat-insulating supports, *S*, so that direct contact with the copper container does not take place. Two tight-fitting copper lids, *L*,*L'*, complete the apparatus. Differential thermocouples, *X* and *Y*, are used to measure the temperature difference between the specimens and the copper

container, and a thermocouple, Z, enables the temperature of the container itself to be measured.

The apparatus is heated in a tubular wire-wound furnace, to a temperature well in excess of that at which the transformation starts on cooling, and the specimens are soaked until the tempera-

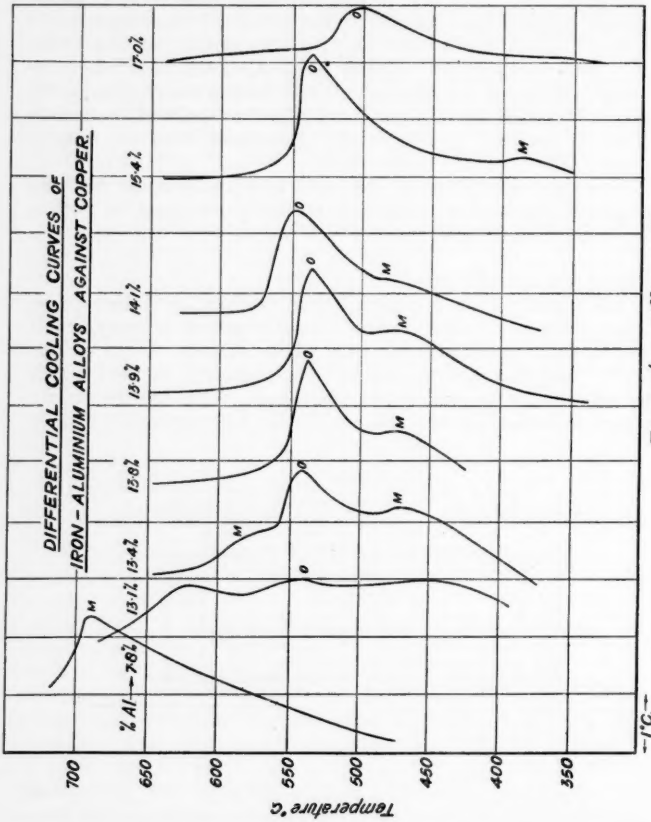

FIG. 2.

ture difference between the specimens and the container vanishes. The power is then switched off and the furnace allowed to cool. The cooling rate, which was governed entirely by the design of furnace, varied from 1·7° C. per min. at 600° C. to 0·9° C. per min. at 350° C., and was the same for all the specimens. Measurements are made of $(T_1 - T_3)$, $(T_2 - T_3)$ and T_3 against time.

These data provide all the standard cooling curves, *i.e.*, the direct, inverse rate and differential.

Results.—In Fig. 2 are plotted the usual differential type of cooling curves for each alloy investigated. They were obtained from the three cooling curves $(T_1 - T_3)/t$, $(T_2 - T_3)/t$, and T_3/t determined experimentally. It is clear that a variety of transformations occurs in the alloys in the range of temperature examined; none of them, however, corresponds to an evolution of heat at a constant temperature, since this would be revealed by a part of the curve being parallel to the abscissæ. In cases where no latent heat is evolved at a particular temperature it is legitimate to consider that changes in the cooling rate are due to variations in the specific heat produced by the transformations in the alloy. The differential cooling curve bears no simple relation, however, to the specific-heat/temperature curve, especially in regions of temperature over which different transformations overlap. It is for this reason that the experimental method used has been complicated in taking such a curve in order to obtain an approximate specific-heat curve.

Double Differential Cooling Curve.

In Fig. 3 are plotted the differential cooling curves obtained

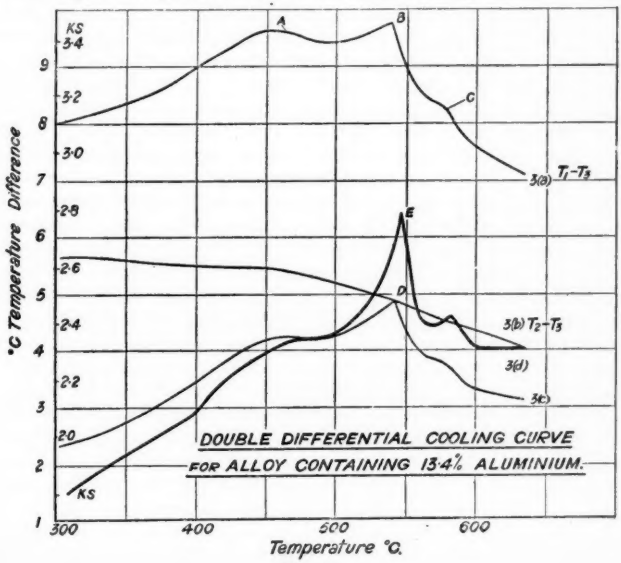

FIG. 3.

for the 13·4 per cent. aluminium alloy 3(*a*) and the copper specimen 3(*b*) with respect to the container ; the curve 3(*a*) is very similar to the ordinary differential cooling curve 3(*c*). By calculation, according to a method already described elsewhere,[11] the specific-heat/temperature curve 3(*d*) is obtained. Owing to certain experimental difficulties, this curve is only approximate ; it gives accurately the rate of change of specific heat at any particular temperature, and thus enables the various transformations to be sorted out much more easily than the ordinary differential curve, and, in particular, gives precise and reliable information regarding the temperature at which the increase in specific heat produced by a transformation is a maximum.

According to curve 3(*d*) a transformation starts at about 600° C., reaches a maximum at 582° C. and then falls off. A second transformation starts at 570° C., attains a very sharp maximum at 548° C. and then rapidly diminishes. Superimposed on this is a third effect, starting at 490° C. and producing a maximum at 470° C.

Curve 3(*c*), whilst roughly similar to 3(*d*), is much less easy to interpret, and gives the maxima displaced ; the displacement varies with the cooling rate, although the maxima on the specific heat curve are practically independent. Provided that the cooling rate is reasonably slow (1° C. per min., say), the ordinary phase change takes place at a constant specific temperature ; changes in the iron-aluminium alloys cover a range of temperature extending, in some cases, up to 300° C. The beginnings and maxima of such transformations are determined much more easily from curves of the type 3(*d*) than from the type 3(*c*). In either case it is difficult to fix the end, as the transformations gradually die out at low temperatures.

Thus, whilst the general trend of the behaviour of the alloys can be judged from Fig. 2, the authors prefer when describing the beginning and maximum points of a transformation, to take such measurements of temperature from the specific-heat rather than the differential cooling curve. In this way a more reliable correlation with magnetic and electrical measurements is, in their opinion, possible.

The Order-Disorder Transformation.

Having determined the presence and position of transformations by means of thermal curves, the problem then resolved itself into an attempt to discover their character. The sharp peaky maxima occurring between 500° and 550° C. were of the kind to be expected on the Bragg-Williams theory, and, moreover, they occurred only within the range of composition throughout which the electrical resistivity could be modified by heat treatment. It was reasonable, therefore, to conclude that the atomic

rearrangement process was responsible for these maxima (marked *O* in Fig. 2). The results are given in Table II.; the temperatures refer to the maxima on the specific heat curves.

TABLE II.—*Maxima on Specific-Heat Curves.*

Composition, Aluminium. %	Temperature.	
	Cooling.	Heating.
13·1	550° C. (feeble).	Not determined.
13·4	548° C., 546° C.	,, ,,
13·8	542° C.	,, ,,
13·9	538° C., 540° C., 537° C.	540° C.
14·1	553° C., 556° C.	Not determined.
15·4	545° C., 545° C.	545° C.
17·0	518° C. (feeble).	Not determined.

In each case the transformation on cooling started at a temperature from 20° to 30° C. higher than that corresponding to the maxima on the specific-heat curves. The relative change in specific heat at the beginning of the transformation varied with the composition of the alloys, as would be expected; for the Fe_3Al alloy, *i.e.*, 13·9 per cent. of aluminium, the increase is about 50 per cent., or roughly twice that predicted by the Bragg-Williams theory. This agreement in the order of the effect is very satisfactory in view of the simple assumptions involved in the theoretical argument.

Reliable heating curves are difficult to obtain, owing to experimental difficulties in controlling the heating rate, *i.e.*, the smaller transformations, marked *M* in Fig. 2, produce an effect on the differential heating curve of the same order as effects due to variations in heating rate. In the order-disorder change the amount of heat absorbed is sufficiently large for a reliable temperature determination to be obtained, and for two alloys measurements are given in Table II. The heating rate was 1·8° C. per min.

Since the maxima on heating and cooling occur at practically the same temperature, there can be very little hysteresis in the process of atomic rearrangement at temperatures of the order of 500°–550° C. when the rate of change of temperature is as low as 1° C. per min. The transformations in the 13·1 per cent. and 17 per cent. alloys were much weaker than the others; this is in agreement with the fact that the degree of atomic rearrangement possible is not so high as in the 13·9 per cent. alloy (Fe_3Al).

In order to prove conclusively that these transformations are in fact due to atomic rearrangement, a series of resistivity measurements was carried out on specimens quenched from

various temperatures. The specimens, in the form of rods 5 in. long and $\frac{1}{4}$ in. in diam., were suspended inside a thick copper tube in a well lagged furnace, heated to 700° C. and soaked for 20 min. (Previous experience had shown that the effect of any previous heat treatment could be eliminated in this way.) They were then cooled by means of an automatic regulator at a uniform rate of 30° C. per hr. to various temperatures at which they were quenched. The thermocouple used to regulate the furnace was placed between the copper tube and the furnace tube, whilst the temperature of the specimens was measured by means of

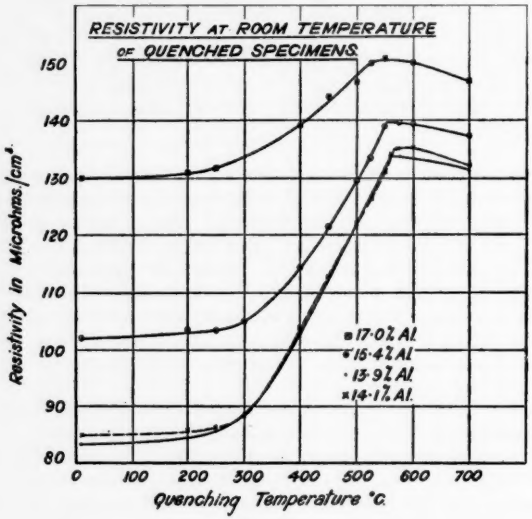

FIG. 4.

another couple placed inside the copper tube. The arrangement for quenching was such that the mean temperature of the specimen did not fall by more than 1° C. before the specimen was in contact with the water. The results are plotted in Fig. 4 for a number of different alloys.

All the determinations made on one alloy lie on a smooth curve, which shows a sharp break. In the 13·8,* 13·9, 14·1 and 15·4 per cent. alloys the break occurs at about 560°C., whilst in the 17 per cent. alloy it occurs at about 525° C. These temperatures fit in very nicely with the results obtained from the cooling

* The curve of the 13·8 per cent. alloy lies in between that of the 13·9 per cent. and 14·1 per cent. alloys, and for the sake of clarity is not shown in Fig. 4.

curves if the reasonable assumption be made that the ordering process affects the specific heat and electrical resistance simultaneously (they are intermediate between the beginning and maximum temperatures—*see* Table II.). The general agreement between the 13·8, 13·9 and 14·1 per cent. alloys is additional evidence of their similarity of composition.

The downward slope on the right-hand side of the break in these curves raises a very interesting point. Above 560° C. the alloys are completely disordered, so that the resistivity of a specimen quenched from any higher temperature might be expected to be independent of the quenching temperature, *i.e.*, the curve above the break should be parallel to the abscissæ. The rate of cooling through 560° C. when quenched from 700° C. is in all probability less rapid than that obtained by quenching from 560° C., owing to the formation of minute vapour films, thus permitting a greater degree of order in an alloy quenched from 700° C. than in one quenched from 560° C. This suggests the possibility that all the alloys, even in the most rapidly quenched condition, are to a certain extent ordered.

Magnetic Transformations.

Isawa and Murakami[4] have shown that the magnetic change point in iron is lowered by the addition of aluminium, and consideration of their results suggested that possibly the other transformations observed by the authors were magnetic in character. However, the agreement between their results and the authors' was not very good, and in any case they had reported no alloy having two magnetic change points; consequently it seemed advisable to repeat their work.

The experimental apparatus consisted of two small tubular furnaces* having windings of the same number of turns which were connected in series. A search coil was wound round each furnace, and the two were connected in opposition through a galvanometer. The number of turns on the search coils was adjusted so that a reversal of current through the heater windings produced no deflection on the galvanometer when both furnaces were empty.

Resistivity experiments prove that the atomic rearrangement process requires a finite time to produce equilibrium at any given temperature, and whilst this period is small in the neighbourhood of the critical temperature (560° C.) it rapidly becomes appreciable as the temperature is reduced. Consequently, magnetic measurements to be comparable with the curves in Fig. 2 should be determined at comparable cooling rates. A series of magnetic curves was taken at a cooling rate of approximately 1° C. per min. This necessitated a gradual decrease in heating, and there-

* Tubular fire elements are a cheap and convenient form of furnace for this purpose.

fore magnetising, current during the course of the experiment, which would have affected the shape of the magnetic curve obtained. To eliminate this trouble a switching arrangement was used so that reversals could always be made with a constant field of 12 gauss, corresponding to a magnetising current of 1 amp.

At low values of the permeability the deflection obtained on the galvanometer is directly proportional to the magnetic induction in the specimen ; at high permeabilities the shape of the specimen takes control in such small magnetising fields, and therefore the magnetic curves can only be used to determine accurately the Curie point and the temperature at which the magnetic induction starts to rise rapidly from a low value.

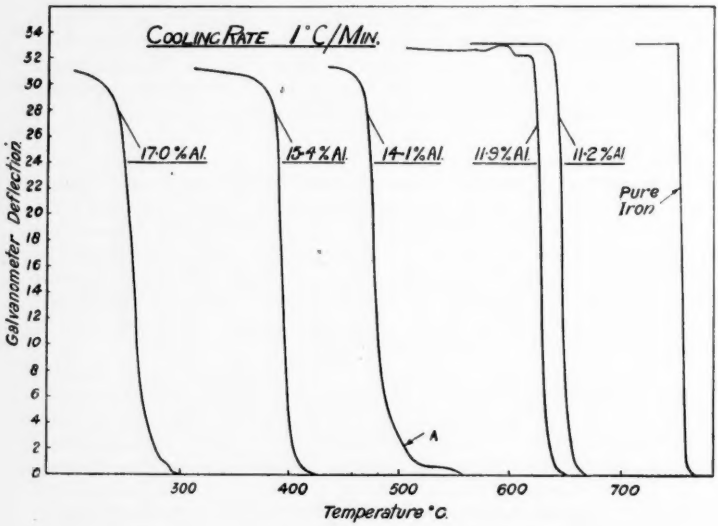

Fig. 5.

Results.—Fig. 5 shows the curves obtained for various alloys over a wide range of composition, taken at a cooling rate of approximately 1° C. per min. The specimens were soaked at 700° C. for 20 min. before the cooling curve was started. Heating curves at a heating rate of 1° C. per min. were also obtained ; in this case the initial condition of the specimens was as cooled to room temperature at 30° C. per hr. The heating curves were exact replicas of the cooling curves within the limits of experimental error (*viz.*, about 2° C.). For the alloys dealt with in

Fig. 5 it is seen that the addition of aluminium lowers the Curie point and that the alloys resemble pure iron in showing no thermal hysteresis at the Curie point.

It is of considerable significance to contrast the absence of thermal hysteresis in the above alloys with the marked hysteresis in alloys containing 13·4, 13·8 and 13·9 per cent. of aluminium. Fig. 6 gives the magnetic curves for the 13·9 per cent. alloy, the

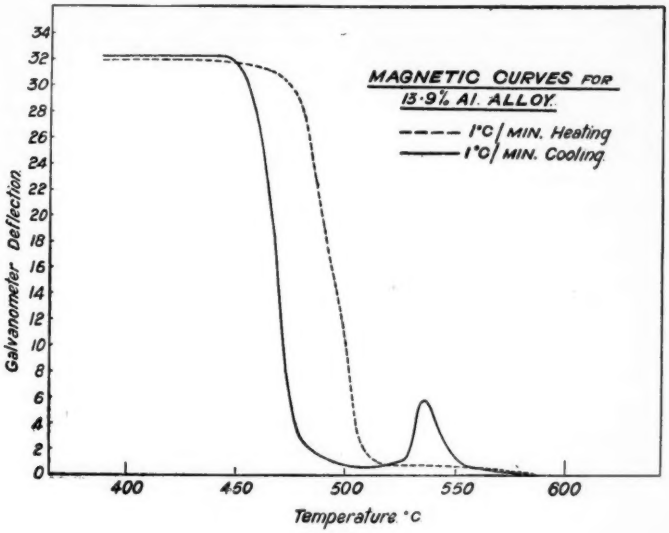

FIG. 6.

heating curve being quite different from the cooling curve. The 13·8 per cent. alloy gave almost identical results.

Fig. 7 shows the effect of increasing the rate of temperature change tenfold. Four different experiments are included to give an idea of the reproducibility of the results; the two heating curves are in good agreement with each other, as are the two cooling curves, but the hysteresis is quite definite.

Fig. 8 shows three cooling curves taken on the 13·4 per cent. alloy. The alloy was stabilised at the high temperature (700° C.) before each curve was commenced.

Correlation Between Magnetic and Cooling Curve Results.

The change from the paramagnetic to the ferromagnetic state gives rise to an evolution of heat which should be visible on the curves shown on Fig. 2. Comparison of magnetic curves with

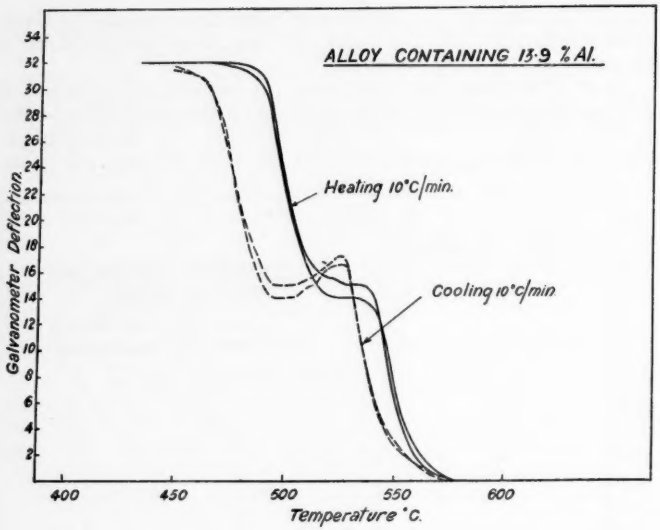
ALLOY CONTAINING 13·9 % Al.
Heating 10°C/min.
Cooling 10°C/min
Galvanometer Deflection
Temperature °C.
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
400
450
500
550
600

FIG. 7.

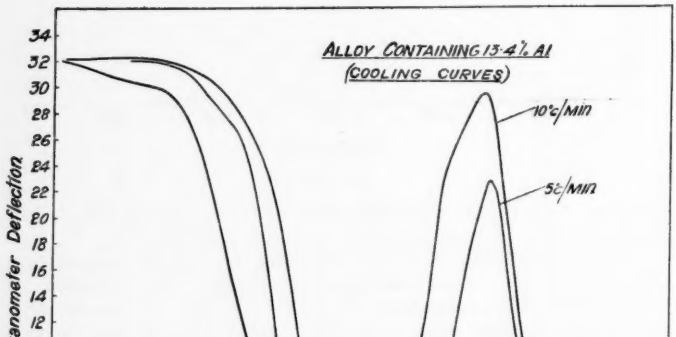
ALLOY CONTAINING 13·4 % Al
(COOLING CURVES)
10°c/min
5c/min
1c/min
Galvanometer Deflection
Temperature °C.
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
400
450
500
550
600

FIG. 8.

the corresponding cooling curves shows that the commencement of heat evolution from the magnetic transformation occurs in the cooling curve at a temperature which corresponds to the foot of the magnetic curve, *e.g.*, in the 14·1 per cent. alloy the magnetic transformation starts at about 500° C. on the cooling curve, which corresponds to the point *A* on the magnetic curve (*see* Fig. 5). The magnetic changes would be expected to affect the cooling curve only when the rate of change of magnetisation is appreciable; in the case of the 14·1 per cent. alloy very little heat due to magnetisation is to be expected in the temperature range along the foot of the magnetisation curve.

Comparison of the magnetic curves of the alloys with that of pure iron shows that the foot on the former curves is always longer than that for pure iron. The difference in temperature between the normal Curie point as determined magnetically and as determined by cooling-curve methods is thus accentuated.

The 13·4 per cent. alloy will now be considered. According to curve (*a*) in Fig. 8 the rate of increase in magnetisation becomes appreciable at 596° C. and again at 485° C., in good agreement with the beginning of the rise on the right-hand side of the two subsidiary maxima on the specific heat curve, curve 3(*d*) in Fig. 3. Similarly, on cooling from 575° C. there is a rapid decrease in magnetisation, which should correspond to an absorption of heat. This explains the fall on the left-hand side of the small subsidiary maximum at 580° C. on the cooling curve.

It will be found that all the transformations indicated in Fig. 2, apart from those shown to be due to disorder-order changes, can be ascribed, by reference to the magnetic curves, to magnetic transformations; consequently the nature of all the transformations has been established.

Magnetic Change Points (General).

Neglecting for the moment the question of hysteresis, the Curie points of the various alloys, *i.e.*, the temperature at which the alloys become ferromagnetic, can be obtained from the magnetic curves. The rate of cooling does not affect this temperature appreciably, even in alloys showing marked hysteresis in their magnetic curves, *e.g.*, such alloys on heating lose their ferromagnetism at a slightly higher temperature than they regain it on cooling; the difference in temperature is not greater than 5° C. It is interesting to note that the very long foot at the base of the curve for the 14·1 per cent. alloy (*see* Fig. 5) was also found by Isawa and Murakami for an alloy containing 14·13 per cent. of aluminium; it does not occur in any other of their magnetic curves for alloys containing 3·96, 9·20, 15·65 and 17·16 per cent. of aluminium. They had no specimens in the range of composition 13–13·9 per cent., where the hysteresis effects occur.

Discussion of Results.

The authors have collected the experimental data recorded in this paper together with those given by Isawa and Murakami and used them as a basis for Fig. 9.

Curve 9(*a*) gives the temperature at which the specific heat is a maximum in the order-disorder transformation.

Curve 9(*b*) is that established by Isawa and Murakami for the variation in the Curie point with the change in aluminium content. Actually, as the present experimental results show, the magnetic phenomena in these alloys are much more complicated than would be assumed from curve 9(*b*) and the authors prefer to present their results on the magnetic transformations in the form of two curves, 9(*c*) and 9(*d*).

Curve 9(*c*) refers to the Curie point of disordered alloys, *i.e.*, it deals only with alloys which become magnetic before they have cooled to the critical temperature at which atomic rearrangement starts. Consequently curve 9(*c*) lies above curve 9(*d*).

Curve 9(*d*) deals with the Curie points of ordered alloys. The points shown are the ordinary Curie points for the 15·4 and 17·1 per cent. aluminium alloys, whereas the points marked with a ringed cross refer to the temperature at which a second rapid rise in the magnetisation occurs in the alloys containing 13–14 per cent., which are anomalous.

By means of this method of representation it is possible to show graphically practically the whole of the experimental data available on the transformations in these alloys. The precise significance of these curves will now be dealt with in detail.

Curve 9(*a*). *The Order-Disorder Transformation.*—The representation of a phase change on a thermal equilibrium diagram presents very little difficulty, since for any given alloy it takes place at a definite temperature. The order-disorder transformation is more difficult to include in such a diagram. At the beginning of the atomic rearrangement process the specific heat commences to increase ; after a temperature interval of 20°–30° C. the specific heat attains a maximum, and then decreases over a very large temperature interval. The only temperature which is well-defined experimentally is that at which the specific heat is a maximum ; and it is for this reason that the authors have chosen this particular temperature to describe the transformation. Provided that the general nature of such transformations is remembered, this method of representation is reasonably satisfactory.

Curve 9(*a*), then, gives the effect of composition on the temperature at which the specific heat curves show a maximum due to the order-disorder transformation. The curve is drawn in two portions, one dealing with alloys containing less than 25 per cent. of aluminium by atoms, and the other with alloys having aluminium in excess of 25 per cent. ; the two portions are connected by a short dotted line. There is a minimum at

Fe_3Al, and there is a marked difference between the 13·9 per cent. and the 14·1 per cent. aluminium alloys, *i.e.*, 15° C., which is much greater than the experimental error.

The curve 9(*a*) might reasonably be expected to be similar to that for the Cu_3Au series of alloys, which is flat-topped with a maximum at the composition Cu_3Au. Haughton and Payne,[13] who established the curve for Cu_3Au, showed that a minimum instead of a maximum was obtained if the alloys contained a trace of oxygen, and the authors cannot dispute that some such explanation may be correct for the Fe_3Al alloys. However, so far as silicon and carbon impurities are concerned, the 13·9 and 14·1 per cent. alloys are identical, and, since the raw materials

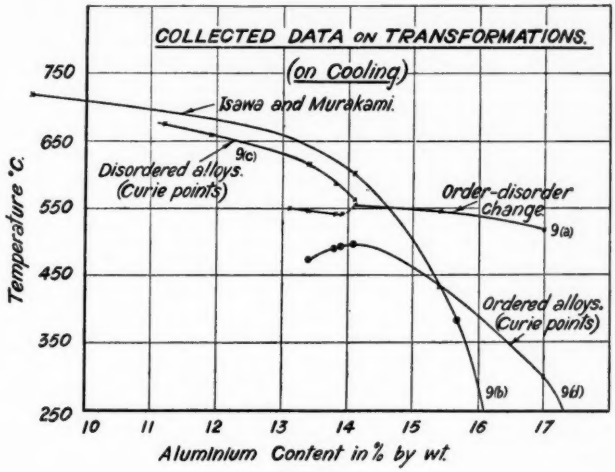

FIG. 9.

and methods of manufacture used were the same, it is difficult to see how the chemical composition *per se* can be different except in aluminium and iron. It should be noticed also that the resistivity curves of these two alloys show a similar difference in temperature of the transformation. Expansion curves, which show a point of inflexion at the order-disorder transformation, also show the same difference (*see* Fig. 10). These latter experimental facts prove with certainty that all the specimens, irrespective of shape and treatment, taken from one ingot have identical properties and eliminate the possibility of variation due to such causes.

It will be seen from the subsequent discussion that the structure produced in quenched alloys changes on passing through the

Fe_3Al composition, and this, in fact, is accompanied by a discontinuous change in the lattice spacing at Fe_3Al.[14] Moreover, in the range from 13·8 to 14·1 per cent. the ordering process and magnetic changes occur at approximately the same temperature. It is possible that these two processes do not proceed independently of one another, and some form of interaction may take place. This type of complication does not exist in non-magnetic alloys such as Cu_3Au. At the present stage therefore the authors prefer to present curve 9(*a*) in the form of two sections, rather than to draw a single curve through all the points, since, in their opinion, this latter procedure is not justified by the experimental evidence.

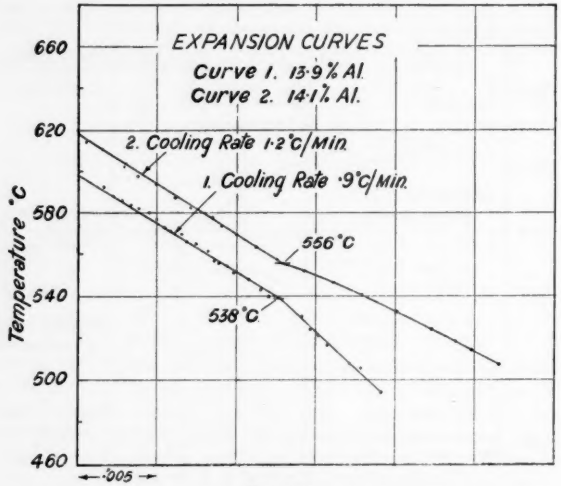

FIG. 10.

Curve 9(*c*). *The Curie Points of the Disordered Alloys.*—Figs. 5, 6 and 8 give the temperatures at which the various alloys investigated become magnetic on cooling, *i.e.*, the Curie points. When the Curie point lies at higher temperatures than that corresponding to the maximum specific heat in the disorder-order transformation, it must refer to the disordered alloy. All such cases have been collected and plotted in curve 9(*c*). The curve must continue on the left-hand side and finally attain 760° C. for pure iron, but the authors have no experimental points corresponding to aluminium contents of less than 11·2 per cent. The right-hand side of the curve ends at 14·1 per cent. The Curie point of a disordered alloy is not necessarily the same as that of the same alloy in the ordered condition, consequently

it is not legitimate to fit the points corresponding to 15·4 and 17·0 per cent. on curve 9(*c*), since these alloys must be partially ordered when they become magnetic.

Curve 9(*d*). *The Curie Points of the Ordered Alloys.*—Before discussing curve 9(*d*) in detail, reference must be made to the peculiar shape of the magnetic cooling curves in Figs. 6, 7 and 8, which are quite different in character from those shown in Fig. 5. Consider curve (*a*) in Fig. 8 in detail ; the alloy becomes magnetic at about 610° C., at 596° C. its magnetisation rapidly increases, and it attains a maximum at about 575° C. The problem is to explain why the magnetisation then decreases. It is significant that the anomalous magnetic curves are obtained only on alloys in which the Curie point for the disordered alloy lies very near to the temperature at which the specific heat for the order-disorder transformation is a maximum.

Whilst the nature of ferromagnetism is not entirely understood, it is generally accepted as being a property of aggregates of suitably oriented atoms. It seems reasonable to suppose that the ordering process which is concerned with the introduction of aluminum atoms into certain preferred positions in the iron lattice, can disturb these ferromagnetic aggregates and cause them to lose their ferromagnetic properties. If this assumption is correct then the type of atomic interchange produced by the order-disorder transformation is sufficient at 575° C., in the case of the 13·4 per cent. alloy (*see* Fig. 8, curve (*a*)), to disturb the ferromagnetic aggregates and render the alloy only feebly magnetic. The small subsidiary maximum on the specific-heat curve at about 580° C. is produced by these changes in magnetisation. At a lower temperature the alloy becomes magnetic again in a more or less normal way in the partially ordered state.

The supposition that the ferromagnetic aggregates can be disturbed by the ordering process is substantiated by the curves in Fig. 8. At cooling rates of the order of 1° C. per min. the degree of order in the region of the temperature at which rearrangement commences is in all probability almost identical with the equilibrium degree of order. At cooling rates of 10° C. per min. this is probably no longer true, with the result that magnetic aggregates formed in the disordered alloy will suffer less interference due to order-disorder transformations than in the slowly-cooled alloy. Consequently as the cooling rate is increased the specimen would be expected to become more magnetic in the disordered state, and to commence to lose its magnetism at a gradually decreasing temperature. Fig. 8 shows this effect, and a similar result is obtained from a comparison of the magnetic curves obtained on cooling the 13·9 per cent. alloy at different rates (*cf.* Figs. 6 and 7).

To return to curve 9(*d*), the points marked with a cross for

the 15·4 and 17·0 per cent. alloys are obtained from Fig. 5; they refer to the partially ordered alloys as already explained. The other four points, marked with a ringed cross, correspond to the temperatures at which the second rise in magnetisation takes place. In accordance with the authors' interpretation they are the Curie points of the partially-ordered alloys. The justification for connecting the two normal points with the other four rather arbitrary points lies only in the fact that all refer to the magnetic transformation in partially-ordered alloys, and as such are of a similar character.

Summary of Fig. 9.—Alloys containing less than 13 per cent. of aluminium do not show any appreciable amount of atomic rearrangement; consequently such alloys give the normal type of curve similar to that obtained for pure iron. Alloys with from 13 to 14 per cent. are subject to atomic rearrangement almost immediately after becoming magnetic in the disordered state. They tend to become non-magnetic again, according to the authors' assumption, owing to the rearrangement process; finally, they regain their magnetism in a more or less normal way at a lower temperature corresponding to curve 9(*d*).

For a given cooling rate the height of the first maximum on the magnetic curve depends on the temperature interval between the Curie point of the disordered alloy and the temperature at which the ordering process starts; as this temperature interval decreases the maximum decreases, so that in the 14·1 per cent. alloy, where the interval is negligible, a long flat only is obtained. Alloys containing more than 14·1 per cent. would only become magnetic in the disordered state at a temperature well below that at which the ordering process starts; such alloys therefore can only be expected to show one Curie point corresponding to the partially-ordered alloy.

This description of the experimental results is by no means exhaustive, and a more detailed explanation is not yet forthcoming. The incidence of order appears to follow the same law as the incidence of ferromagnetism. Both processes are brought about by changes in internal energy, and therefore affect the resistivity and specific heat. Consequently it is not easy to separate the two effects experimentally. Moreover, a careful study of the details of other experimental results not recorded in this paper suggests that in the range of composition from 13·4 to 14 per cent. the two processes are not independent; more quantitative magnetic data are required to clear up these points.

Hysteresis in Magnetic Curves.

This phenomenon is restricted to alloys containing 13·4–13·9 per cent. of aluminium. A special series of experiments was

carried out on the 15·4 per cent. alloy at heating and cooling rates of from 1° to 10° C. per min. No appreciable hysteresis was observed. In this alloy the Curie point is well below the critical temperature for the order-disorder transformation, yet cooling from 600° C. or even quenching does not appreciably affect the magnetic curve.

If it be assumed that the magnetic properties of an alloy depend on the degree of order, then hysteresis in alloys containing from 13 per cent. of aluminium upwards is to be expected. On cooling, the degree of order will be less than the equilibrium degree of order, and on heating it will be greater at any given temperature. It is of considerable significance therefore that this hysteresis effect is restricted to alloys containing not more than 25 per cent. of aluminium by atoms. The 14·1 and 15·4 per cent. alloys

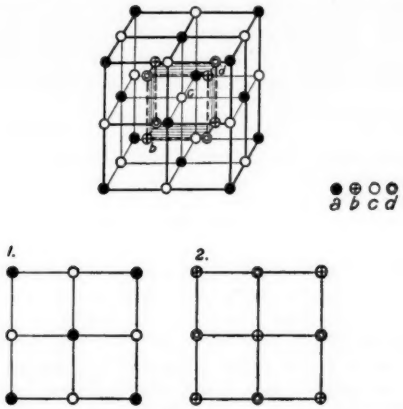

FIG. 11.

must be subject to considerable atomic rearrangement on cooling (*cf.* Fig. 4, which shows that large changes in resistivity in these alloys are produced by heat treatment), yet their magnetic curves show no hysteresis.

Bradley and Jay's results are very interesting in this connection. They found that alloys containing slightly less than 13·9 per cent. of aluminium when quenched showed a completely disordered structure. On the other hand, with aluminium in excess of 13·9 per cent. the quenched structure showed a type of order corresponding to FeAl.

These results can be expressed in the following way : Consider the body-centred lattice of the iron-aluminium alloy as consisting of two simple cubic lattices, the one being displaced half way

along a diagonal of the other. Draw one plane of each lattice (*see* Fig. 11), and call alternate positions in lattice (1) *a* and *c*, and in lattice (2) *b* and *d*. Bradley and Jay showed that for alloys containing less than 13·9 per cent. of aluminium the structure as quenched from 600° C. showed a random arrangement, *i.e.*, the aluminium atoms were found in positions *a*, *b*, *c* and *d* without preference—a typical disordered structure. The slowly-cooled structure of Fe_3Al showed that the aluminium atoms tended to go entirely into the *b* positions. In alloys containing less than 25 per cent. of aluminium by atoms the ordered structure similarly showed substantially all the aluminium atoms in the *b* position.

For alloys containing more than 25 per cent. by atoms the quenched structure showed a preferential arrangement of aluminium atoms. The positions *a* and *c* were devoid of aluminium atoms, which were distributed at random in *b* and *d* positions. In these alloys, then, one lattice is always iron, and transitions from lattice (1) to lattice (2) cannot be prevented by quenching.

The annealed structure again showed a majority of aluminium atoms in the *b* positions.

Whilst there is no discontinuity in the annealed or ordered alloys at Fe_3Al, there is a discontinuity in the quenched alloys. Transitions from lattice (1) to lattice (2) can be prevented by quenching, provided that the aluminium content of the alloy is less than 13·9 per cent. ; with higher contents this is no longer possible.

If, therefore, the magnetic properties are principally affected by changes in internal structure corresponding to transitions along a diagonal, *i.e.*, from one lattice to the other, then hysteresis is to be expected below 13·9 per cent. aluminium, but not above.

There is no marked discontinuity[12] in curves showing the variation of resistance with composition, either in the quenched or the annealed condition. This suggests that resistivity changes are primarily concerned with transitions from *d* to *b* and not with transitions from one lattice to the other.

Conclusion.

It is clear from the experimental results described in this paper that alloys of approximately the composition Fe_3Al possess many interesting and hitherto unsuspected properties.

Whilst the general nature of the transformations has been established, the phenomena observed are extremely complicated, and further experimental work seems desirable in order that a complete explanation may be developed.

The authors thank the Metropolitan-Vickers Electrical Co., Ltd., for providing the facilities necessary for the experimental

work and for permission to publish it, and, in particular, Mr. A. P. M. Fleming, Director, and Manager of the Research and Education Departments, for his personal interest in its progress.

They are indebted to Professor W. L. Bragg, F.R.S., for his kind interest throughout the course of the investigation.

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THE IODINE METHOD FOR THE DETERMINATION OF OXIDES IN STEEL.*

By T. E. ROONEY and A. G. STAPLETON (National Physical Laboratory).

SUMMARY.

A method is described for the estimation of oxides in steel by the solution of a sample in alcoholic iodine solution.

Details of the apparatus and the procedure necessary for obtaining correct results are given.

Results are shown with two types of filter.

THE iodine method for the estimation of oxides in steel may be described as a "residue method." It consists in dissolving a sample of drillings in a solution of iodine, filtering, igniting and weighing the insoluble residue. The ignited residue is examined for silica, oxides of iron, manganese and aluminium, &c. Various modifications of the method have been proposed which differ mainly in the composition of the iodine solution. Willems[1] used an alcoholic iodine solution and filtered through an ultra-filter in order to retain very fine particles of the residue. This method has been elaborated by B. A. Bannister in a thesis at Sheffield University and was introduced to the National Physical Laboratory by Dr. C. H. Desch, F.R.S.

As a result of the experience gained in the use of the method at the National Physical Laboratory the apparatus and procedure have been somewhat modified. The modified apparatus is illustrated in Fig. 1. The main alterations consist in the use of a small mercury safety trap for the nitrogen stream, the introduction of a silica-gel tower at *A* and the use of a "dry" purification train for the nitrogen in place of the alkaline pyrogallol used by Bannister. Silica-gel was also substituted for the soda-lime used by Bannister in the tower at *B*. As the success of the method depends on the exclusion of all traces of moisture from the apparatus and the reagents, the efficiency of the gas purification train is very important, and the use of soda-lime as an acid trap at the end of the train is rather risky. The removal of traces of oxygen may not be so important but it is an additional safeguard. Another point worthy of mention is that only dry gas is allowed to enter the apparatus through tap *C*, and evacuation

* Communication from the National Physical Laboratory, received February 12, 1935.

FIG. 1.—Apparatus for the Estimation of Oxides in Steel by the Iodine Method.

is carried out only through tap *D*. This obviates any risk of contaminating the apparatus by moisture and other vapours carried away during evacuation.

The nitrogen is purified by passing through a U-tube containing soda-lime in order to remove traces of carbon dioxide. It is then dried by bubbling through concentrated sulphuric acid, and passes into a combustion tube which is maintained at a temperature of 600° C. The combustion tube contains spirals of copper gauze and of pure nickel gauze. From this tube the gas passes through another sulphuric acid bottle, and then into another combustion tube containing pure iron turnings which are maintained at a temperature of 800° C. The sulphuric acid bottles are provided with safety traps. Finally the nitrogen is conducted through a tower containing silica-gel before entering the apparatus through a tap at *F*. A by-pass at *E* is provided with a tap. The delivery tube is divided into two branches so that nitrogen can be admitted through the taps *C* or *N*. The apparatus can be evacuated through the tap *D*.

The sample is used in the form of millings and great care is exercised in their preparation. A special milling machine is employed which is reserved for those purposes in which it is essential to avoid contamination during the preparation of a sample for analysis (pure metals, &c.). The machine is enclosed in a cubicle in order to ensure freedom from dust and moisture. A cleaning cut is made so as to remove any effects of surface oxidation or other contamination. Immediately the millings have been prepared they are carefully dried in a stream of nitrogen. A portion is then inserted in the weighing bottle *G*, weighed and transferred through the tap *H* into the reaction vessel *J*. The bottle is re-weighed. The reaction vessel is placed in a horizontal position, the millings are spread out as much as possible and a slow stream of dry nitrogen is passed through by connecting to the by-pass at *E*. The gas stream is continued overnight in order to displace the air and thoroughly dry the vessel and its contents.

Seventy grammes of pure iodine, previously dried by storing over silica-gel, are placed in the tap funnel *K* and dissolved in 600 ml. of pure dry methyl alcohol. Anhydrous methyl alcohol is a commercial product and has been found to be much more reliable than ethyl alcohol for this purpose. To ensure that it is free from traces of moisture it is distilled two or three times over calcium.

The iodine solution is filtered through either a "Cella" ultra-filter or a No. 50 Whatman filter. The filter is dried by soaking in methyl alcohol for about 10 min., blotted between filter paper and fitted between the flanges at *L*. The flanges are first smeared with vaseline and are held together by means

of spring clips to ensure a tight joint. The filter is supported on a perforated glass disc, but here again an improvement can be effected by the use of a fritted-glass disc with fused edges which speeds up the filtration. The filter is washed three or four times with methyl alcohol with slight suction, the filtrate being received in the vessel *P*. The apparatus is then assembled as shown in Fig. 1, the taps at *R*, *H* and *M* being closed. The tap at *C* is closed and that at *D* opened. A slow stream of nitrogen is allowed to enter at tap *N* in the funnel *K*. The taps at *R* and *H* are opened and the iodine solution is filtered into the reaction vessel with slight suction. Tap *H* is closed near the end of the filtration so as to retain a slightly reduced pressure in the reaction vessel. The reaction vessel is then disconnected and fixed securely in a felt-lined wooden box. The box is mounted on trunnions and is slowly revolved by means of a small geared motor. The iodine solution is thrown from end to end of the reaction vessel. The churning is continued until all the steel is dissolved, usually in about two to three hours. A magnet may be used to determine when solution is complete.

Another filter is prepared as previously described, and the funnel *K* is removed and replaced by the reaction vessel above the filter. The vessel *P* is fixed below the filter. Tap *H* is cautiously opened to admit nitrogen to the reaction vessel, and then tap *M* is opened and the liquid is filtered with slight suction. The reaction vessel is washed down three or four times with methyl alcohol and, after draining, disconnected. The filter is washed with methyl alcohol until free from iodine and suction is continued until the filter is dry. The residue on the filter should be black or dark grey. The edges of the filter which have been clamped between the flanges are difficult to wash free from iodine and should therefore be trimmed off. The filter with the residue is ignited in a small platinum crucible and weighed.

In the procedure described by Bannister the apparatus and filter are dried before each operation by evacuating two or three times and washing out with dry nitrogen. The procedure described above is simpler and safer in operation as there is less risk of moist air leaking into the apparatus, and considerable time is saved. The filtration of the iodine solution into the reaction vessel usually occupies about 20 to 30 min. and the filtration of the liquid after the reaction occupies 40 to 50 min.

As a rule 7 to 8 grm. of millings are used for a determination and 5 to 20 mg. of residue are obtained. The complete examination of these small amounts is still being investigated. Bannister recommended colorimetric methods, but these have not been found satisfactory for traces of alumina. The estimation of small amounts of silica in the presence of relatively large amounts of iron oxide by the hydrofluoric acid method is not satisfactory.

Fusion of the residue with sodium carbonate has also been used, but trouble has been experienced owing to attack of the platinum crucible during the fusion.

In more recent work the residue is digested with concentrated hydrochloric acid. The insoluble portion is filtered off, ignited and weighed. Silica is determined by evaporation with hydrofluoric and sulphuric acid, and the small residue remaining is fused with a little sodium carbonate; the melt is dissolved in hydrochloric acid and added to the main filtrate. Iron is determined by means of the "cupferron" reagent, alumina by means of ammonium benzoate[2] and manganese with bromine and ammonia. As in some cases the weight of the precipitate obtained is very small, careful weighing is necessary and the use of a micro-balance is practically essential.

TABLE I.—*Total Residues.*

Carbon. %	Total Ignited Residue. %	
	"Cella" Filter.	Whatman Filter.
Carbonyl iron.	0·100	0·107
0·10	0·079	0·031
0·40	0·093	0·094
0·40	0·092	0·092
0·40	0·096	0·094
0·60	0·108	0·108

TABLE II.—*Analyses of Residues.*

	Carbonyl Iron.	Steel, Carbon 0·10%.	Steel, Carbon 0·40%.	Steel, Carbon 0·60%.
Weight of sample. Grm.	9·1698	8·3808	8·2732	6·4612
,, ,, residue. Grm.	0·0092	0·0066	0·0076	0·0070
Residue. %	0·100	0·079	0·092	0·108
Weight of SiO_2. Grm.	0·0002	0·0006	0·0008	0·0008
,, ,, Fe_2O_3. Grm.	0·0088	0·0019	0·0040	0·0020
,, ,, Al_2O_3. Grm.	...	0·0018	0·0015	0·0012
,, ,, Mn_3O_4. Grm.	...	0·0026	0·0010	0·0030

In Table I. results for the total residue obtained are given for a number of steels using a "Cella" and a No. 50 Whatman filter.

In Table II. some examples are given of analyses of the residues which illustrate the necessity for careful weighing. As already noted, the analysis of the residues is still being investigated.

In conclusion the authors have to thank Dr. C. H. Desch, F.R.S., for the opportunity afforded of carrying out this investigation.

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DISCUSSION.

Professor A. M. PORTEVIN (Paris) congratulated the authors on a very interesting paper, which he was the better able to appreciate because, in conjunction with Mr. Castro, he had been carrying out studies on the residue method. There were several questions which he would like to put to the authors. They indicated a very careful method for dissolving steels in an anhydrous solution of iodine in methyl alcohol with a view to isolating their inclusions completely, and the results obtained were simply the outcome of an analysis of the residue, without any check. It would be interesting to know how the authors were assured of the value of the process, that was, in what measure the process satisfied a two-fold essential condition: (1) That the oxides would not be attacked by the reagent, and (2) that all the metallic elements of the steel would be dissolved.

The accuracy of the tests was determined by digesting various simple oxides, FeO, MnO and so on, with the reagent and checking the completeness of recovery, and was, he thought, open to question; the reactions in the presence of iron might be completely different, by reason, on the one hand, of electrolytic action due to the presence of the metal, and, on the other, of the heat of the reaction. It would have been useful, if not indispensable, to make comparative estimations by the method of reduction by carbon *in vacuo* or by a residue method, such as the electrolytic method, which gave good results. It was very difficult, moreover, to prove the value of the method in the case of inclusions rich in FeO; it was not yet completely cleared up whether FeO was soluble in pure iron or in extra mild steel. Did the residue methods give the FeO of the inclusions or the total FeO? That was not known. In any case the total oxygen must be greater than the oxygen of the residues.

In short, while it was necessary to be sure that the analysis of the residue compared properly with the real composition, a point to which the authors paid attention, it was also necessary to know—what the authors did not mention—whether the residue was in good correspondence with the total of the inclusions present in the steel and corresponded to them only. Finally, it would be interesting to know if the method could be applied to low- and high-alloy steels.

Dr. C. H. DESCH, F.R.S. (Vice-President, Teddington) said he would like to deal with one or two of the points raised by Professor Portevin. The paper by Rooney and Stapleton described only the experimental improvements which they had made in

the method of determining oxides by the iodine process in question. It did not profess to give any results beyond a few illustrative experiments, but as a matter of fact a number of steels had now been examined both by the method of fusion with carbon *in vacuo* and by the method described by the authors, and those results would form part of the forthcoming report of the Ingots Committee. He would say that on the whole the agreement was good so long as one was dealing with simple carbon steels very low in other elements. He would say, in reply to Professor Portevin, that the method was not applicable to steels containing any appreciable quantity of alloying elements. When chromium was present, chromium carbide was so resistant that it was obtained in the residue, and it was impossible by ordinary analytical methods to say how much represented oxide and how much carbide. There seemed to be no great difficulty with the ordinary steels provided that the sulphur was low. That was the question which it would next be necessary to examine, and with great care—the degree to which the sulphides were left unattacked. With regard to the oxides, he thought it could be said from the experience acquired that oxide of iron was left quite unattacked in the process.

The most important improvement which Mr. Rooney had made was the use of methyl alcohol instead of ethyl alcohol, and, using very carefully dried methyl alcohol, the action on the oxide was negligible, and ferrous oxide was left insoluble as well as manganese oxide. The same, however, could not be said of the sulphides, and when steels containing a high proportion of sulphur were being used it was very difficult to interpret the results ; the residues were too high, and it would evidently be necessary to make a sulphur determination and to make some allowance accordingly. Further experiments would be necessary, however, before the allowance necessary for the sulphur was known.

Mr. E. W. COLBECK (Northwich) thought the authors were to be congratulated on the improvement they had made in the iodine method of determining oxides in steel, and made a plea for further work on the subject. He asked whether the authors would consider reviewing all the available methods for the determination of non-metallic matter in steels. He himself had done a considerable amount of work on the chlorine method and Treje and Benedicks'[1] electrolytic separation. So far as he had been able to ascertain, the chlorine method was quite reliable on the carbon steels for silicon and aluminium oxides, but broke down with regard to the other oxides. That seemed to represent the position arrived at by the authors' modification

[1] *Journal of the Iron and Steel Institute*, 1933, No. II. p. 205.

of the iodine method, and an advance beyond that point was essential.

This determination of non-metallic matter in steels literally bristled with every kind of difficulty imaginable, and the difficulties began long before one ever commenced the actual chemical analysis; the taking of the sample had to be carried out with the utmost care. One of the great difficulties of the chlorine method to which he had referred was to avoid loss of material by dust. That was difficult to avoid, because the drillings were handled so many times. They were handled in the milling machine, and must be handled when being removed for weighing, and there was a chance of error there.

He wondered whether it would be useful if the work could be carried out in conjunction with X-ray and crystallographic examination of the residues for the purpose of indentifying exactly in what way the different oxides were linked up together; because in the work which was being done at the present time, or at all events in a large part of it, the oxides were all returned separately. Undoubtedly, of course, that was not their true form in the steel. The actual combination of the oxides was a matter of some importance and would be well worth investigation.

Mr. W. W. Stevenson (Sheffield) said he would like to congratulate the authors on starting the ball rolling by making a real advance in residue methods. Up to now he did not think there had been a really satisfactory method for the determination of residues. Although the Continent and the United States of America were giving hundreds of oxygen figures by vacuum fusion, one might ask what they meant. To give a figure of oxygen content did not give the form in which that oxygen existed. He had been associated with work on the iodine method for over a year. The writer and his co-workers started on the original Bannister method and made nothing of it, but the authors' modifications had definitely made the method workable. They had examined 50 or 60 steels by the iodine process and the fact that they had had check figures on duplicate determinations in almost every case spoke for itself; there was no other residue method by which that could be done consistently. They had confirmed the authors' work on the "Cella" filter and the Whatman filter, and found that it was correct that equally good results could be obtained either way. They agreed as to the difficulty of analysis in the case of aluminium, and would like to draw the authors' attention to aurine tricarboxylic acid as a colorimetric reagent for small amounts of aluminium.

In Table II. the authors gave silica, ferric oxide, alumina and Mn_3O_4. He would like to tell them that he had found TiO_2, ZrO_2 and lime in quite large quantities in a number of steels.

They could confirm what Dr. Desch said about the action of chromium ; chromium carbide was definitely undecomposable by the solvent. Although in the case of nickel the actual metal was not soluble, an alloy of four parts of nickel to one part of iron was soluble, and hence it might be assumed that nickel steels would be all right.

With regard to the sulphides, they obtained separation of about 90 per cent. of sulphides, and he thought it extremely likely that the sulphides were separated as oxides. He thought that in that case the methyl alcohol did not merely act as a vehicle for the iodine, but was chemically active. In the case of high sulphide steels it was necessary to look for a solvent which contained no oxygen, such as carbon disulphide or trichlorethylene, if it was desired to separate them as sulphides.

He hoped the authors would continue their work and give further results later. Incidentally, his own method of analysis of the residues was very different from that adopted by the authors.

Dr. T. SWINDEN (Sheffield) remarked that opinions still differed as to the value of this and various other methods for the determination of oxides in steel, but there was no difference of opinion as to the necessity of determining, if possible, the identity and quantity of inclusions in steel by direct quantitative methods. The Dickenson method which had had, perhaps, the widest acceptance, had been shown to be of considerable value in the separation of silicate inclusions of an acid type, but quite unsuitable for dealing with the inclusions in, say, mild basic steel. The electrolytic method worked out so thoroughly by Benedicks and Treje had not received very wide support, due possibly to certain difficulties in manipulation, and the fact that the method quantitatively separated all the carbides along with the oxides. He and his co-workers understood that this method had been further improved in the direction of separating the carbides, and that further information in this direction was likely to be available in the very near future.

There was much to be said in favour of microscopic examination and, in the speaker's opinion, no methods of chemical analysis would remove the advisability and the necessity for such microscopic work. He and his colleagues felt, however, that the iodine method was sufficiently reliable to justify very close examination, thanks largely to the work of Mr. Rooney, and they had done a considerable amount of work with it. Details of the actual method would be referred to by other speakers, but he would like to say that they had satisfied themselves as to the reproducibility of the results, at least so far as plain carbon steels were concerned, and the results were beginning to take tangible shape.

He felt strongly, however, that more work was required in regard to the limitations of the method, with particular reference to the interference of special elements for one thing, and the question of what happened to the sulphides. As to the former, although nickel was insoluble in the alcoholic iodine solution, they had found that at least up to 30 per cent. nickel iron alloys were completely soluble. On the other hand, it was quite definite that chromium interfered, and it was probable that other carbide forming elements (with the exception of iron) would lead to higher results being returned. Mr. Rooney did not refer to the presence of lime in his residues, whereas they had invariably found a certain quantity, and they had also established some correlation between the presence of zirconia and titania in steels treated respectively with zirconium and titanium.

As to sulphur, both iron sulphide and manganese sulphide had given a 90 per cent. recovery in the residue, although there were indications that the sulphide appeared to have been decomposed into organic compounds.

There were many other points of detail that still required to be worked out, such, for example, as the relative results obtained when treating drillings, compared with treating a solid piece of steel. Efforts were being made by modification of the method to make it applicable to solid samples.

The alternative method of determining oxides by the vacuum extraction method was also being exploited, particularly by Professor Andrew and by Dr. Desch and he (Dr. Swinden) and his co-workers were on the point of completing the installation of apparatus for this method. They had in mind, particularly, to proceed in collaboration with Dr. Reeve with the work the latter did in America on fractional evacuation. If the results were confirmed, it was felt that this method had great possibilities and was immune from the disadvantages of the iodine method as regards the interference of special elements. They had also done a certain amount of work by the method introduced by Herty, of deoxidising samples of molten steel with aluminium and determining the resulting alumina. They were endeavouring to correlate such results with the slag analyses on samples taken at corresponding times, but, as might be expected from the work presented at this meeting from the Royal Technical College, Glasgow, certain discrepancies occurred. They were, however, pursuing the matter further in view of the great advantages that would accrue if a really rapid, simple and accurate guide could be obtained as to the degree of oxidation of the metal during the process of steel making.

Dr. A. B. Kinzel (New York, U.S.A.) said the discussion had been most interesting and the paper which the authors

presented was a valuable contribution to the subject. The work done in America had been referred to by several of those who had taken part in the discussion, and, as was well known from the literature, there was a wide divergence of opinion as to the value of the various methods which were used. To the best of his belief the iodine method using absolutely moisture-free alcohol had not been used to a large extent in the United States. The iodine method with water solution had been used by many with apparent success. One naturally hesitated to claim success for any of these methods. The fact that silica and alumina could be readily determined was interesting, but it should be remembered that that was true of almost every one of the various methods which were now being used for inclusion analysis. Silica and alumina seemed to offer no great difficulties ; the difficulties came with MnO, FeO and the sulphides.

One interesting point in connection with the water soluble iodine method was that sulphur was precipitated quantitatively as elemental sulphur, which meant that one had a quantitative solution of Mn plus Fe in the sulphides.

One did not know as yet whether the dissolved oxygen and FeO or MnO not present in the inclusions were included in any of the analyses ; that seemed to be a very difficult point. In the work with which he was associated they checked the total oxygen as obtained by aluminium treatment of half a crucible, so as to get the total oxygen in that way, with the iodine method, and the totals corresponded very beautifully, which led them to believe that they did get the dissolved oxygen as well as the oxygen in the inclusions. One might use more than one method to get at the real story.

The U.S. Bureau of Standards and the American Institute of Mechanical Engineers had started a programme of work about a year ago. A number of different steels had been prepared and samples very carefully taken, mixed and so on, and distributed to a number of laboratories in the United States and in Europe. He believed there were some in England. They had had reports on a good many of these, and hoped in about six months' time to have complete reports whereby they could compare the results obtained by the various methods from the various laboratories.

In conclusion, the total analysis by vacuum extraction gave a figure for the total oxygen which was interesting, but not satisfying. One wanted to know what the inclusions were and how they were distributed. When one got the FeO, MnO, the SiO_2 and so on, one still did not know what one would like to know, because one realised that those inclusions were not simple things ; the sulphides were soluble in the silicates and *vice versa*. Then, too, did different types of inclusions affect the physical properties

of the steel differently, and if so, how ? No final answer to the problems had yet been found.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), said he would like to say a few words on the paper from the point of view of the Ingot Committee. The Ingot Committee sat in joint session with the Open Hearth Committee of the British Iron and Steel Federation recently, and held a most productive meeting. The Open-Hearth Committee had some fourteen major problems which they said they wished to solve, and eight of these were dependent on a real knowledge of oxygen in steel. After a good deal of consideration it was thought that it would be a good plan if the Heterogeneity Committee could reinforce the work of independent investigators by an official research. They applied to the Federation Research Council, which granted them £1,000 a year for five years to tackle the question of oxygen ; and he thought Mr. Colbeck, who represented one of the biggest consumers of steel in the country, might be interested to know the determined way in which the steel industry were trying to tackle the question. They had arranged as a committee that half of that money should be spent under the direction of Dr. Desch at the National Physical Laboratory, and the other half at Sheffield University under the direction of Professor Andrew, and the Committee continually discussed oxygen determination in detail much more than had been done that day, and the discussions were also more intimate.

After congratulating the authors on the very excellent paper presented, he would like to explain that the Ingot Committee were in a difficulty from the following point of view. A number of the members of that Committee, amongst whom he was not included, thought that the oxygen method should be perfected and that any money and resources which might be available should be devoted to the perfection of the method, and that work should be carried out for a considerable period of time in perfecting that method, it being assumed that it was not perfect to-day, and it was suggested that that should be done before any results were issued. The Open-Hearth Committee and many people in the industry were anxious, as indeed was everyone, to know what the real oxygen content of the steel was, and there was another section of the members of the Committee who said that they had better publish the oxygen results in their next report, describing in detail the process employed and saying, " These are the results from that process as conducted "—which was, indeed, all that could be done. It seemed to him, judging by the very critical discussions which had taken place in the Committee, that in another thirty or forty years, when the oxygen results were published, the method would still not be absolutely

perfect even then. The figures that one obtained for the determination of an element were really the figures produced by the method available at the time. The vacuum extraction method and the iodine method were the two which were being employed, and he was sure that everyone would have confidence in the investigators in charge of the work, but with the best intentions in the world and with all the ability at their disposal it must be understood that there was not much hope of a great mass of unchallengeable quantitative data on oxygen immediately.

So far as he could ascertain, it seemed to be the feeling of the members of the Committee that the iodine method, when restricted to carbon steels, and when every allowance was made for Mr. Whiteley's valuable suggestion with regard to the influence of sulphur, and when one avoided applying the method to steels containing special elements—and many of the ordinary steels did contain special elements to-day—must be regarded as in the nature of a comparative success at the moment, but he did want to assure Mr. Colbeck and others interested that the matter was having the greatest attention.

He would like to ask how it was possible to check the accuracy of oxygen determinations. It seemed a fair inference that there was probably a distribution of oxide in the " colloidal " condition, and frankly he did not see much immediate hope of solving the matter completely at present. He did look forward, however, to a lot of extremely valuable data from Professor Andrew and Dr. Desch, data provided under conditions which would be accurately described to the Institute, and the members who used those data must make their own qualifications and draw their own deductions. He thought that was the state of the art at the moment.

AUTHORS' REPLY.

In reply to Professor Portevin the AUTHORS wrote that, as indicated by Dr. Desch, the work with the iodine method had been mainly confined to straight carbon steels, and with these the metal was completely dissolved. The carbide was decomposed, and free carbon remained in the residue before ignition.

With regard to attack of the oxides by the reagent, it was highly probable from the results obtained by other methods, as referred to by Dr. Kinzel, that silica and alumina were not attacked. The present method, as compared with aqueous iodine methods, afforded a better recovery of the oxides of iron and manganese. Whether these oxides were recovered in the form originally present in the steel had not yet been definitely proved, but the real question was whether the amount recovered

bore any definite relation to the amount existing in the steel. This question was at present rather obscured by the behaviour of the sulphides, which was being investigated.

The point raised by Professor Portevin with reference to the heat of the reaction was an important one, and had already been considered in connection with future work on the decomposition of the sulphides.

The advantages of the present method over the electrolytic method were that the carbide was decomposed and the method was much simpler to manipulate. Results were being compared with those obtained by the vacuum fusion method, which should enable conclusions to be drawn with regard to the proportion of oxygen or oxides in solid solution.

The authors regarded the method as still being in the research stage, but it was thought advisable to publish the improvements already accomplished for the information of others using the method. This course had been justified by the general discussion and in particular by the remarks of Mr. Stevenson.

Some of the points raised by Mr. Colbeck had already been dealt with at the meeting. He referred to X-ray examination of the residues. A few attempts at X-ray and spectroscopic examination had been made, but the results were not very encouraging so far. By using thin discs it might be possible to avoid some of the difficulties associated with millings, but it would probably be necessary in that case to maintain the temperature developed during the reaction in order to ensure complete solution of the metal. This procedure was worth trying, but it might involve other difficulties, and it would be difficult to introduce pieces into the reaction vessel as illustrated. Another apparatus had, however, been constructed without taps into which relatively large pieces could be easily introduced.

In reply to Dr. Swinden and Mr. Stevenson, lime was found in some of the residues, but the amounts were small and variable, and it was suspected that some lime might have been carried over in the distillation of the alcohol. Attention had, therefore, been confined to the determination of the major constituents of the residue. Small amounts of magnesia had also been detected in some residues. A few experiments with a titanium steel indicated that titanium was separated as carbide, and, therefore, it was difficult to estimate any titanium oxide that might be present.

Dr. Swinden mentioned microscopic examination and Dr. Kinzel said that "one might use more than one method to get at the real story." There could be no doubt, from the complicated nature of the inclusions, that a combination of the available methods, whether chemical or physical, would be necessary for a true understanding of their composition and their effect on the properties of the steel.

One could appreciate the point of view of Dr. Hatfield that the money granted through his Committee should be spent on getting results rather than investigating methods, but there was also the point of view of the investigator who had to churn out results without understanding their meaning and who might be criticised for their lack of meaning. Dr. Hatfield mentioned that his Committee continually discussed oxygen determinations in detail. It would be an advantage if the investigators actually engaged on the estimation of oxygen could meet and discuss their difficulties from time to time. Such a course would undoubtedly help towards a quicker solution of the problem. The authors had been glad to be able to compare experiences of the iodine method with Mr. Stevenson, and there was no doubt that this had been mutually advantageous.

THIRD REPORT OF THE CORROSION COMMITTEE.

By a JOINT COMMITTEE of the Iron and Steel Institute and the British Iron and Steel Federation.

This Report was presented for discussion at the Annual General Meeting of the Iron and Steel Institute on May 1, 1935. It is published separately as Special Report No. 8. The discussion and the Committee's reply are given below.

DISCUSSION.

Dr. W. H. Hatfield, F.R.S. (Chairman of the Corrosion Committee), said that it was his privilege to introduce the Report, but the actual presentation of the different sections would be undertaken by the authors who were responsible for them. Before dealing with the Report itself, he would like to say how very much the Committee deplored the loss of their friend Mr. J. H. S. Dickenson, who died in November last. Mr. Dickenson contributed in a large measure to the work of the Committee, and the Committee felt his loss very much indeed. He was sorry to say that the Committee had also lost another of their members, Mr. F. F. Hunting, who had helped very substantially in the work, and who had died only a few days ago.

He thought it would be clear to everyone who studied the Report that the work had now taken on very large dimensions. There was a very extensive official research going on under the direction of Dr. Hudson, and there were corrosion stations all over the world. That would not have been possible without substantial financial assistance, and he would like, on behalf of the members of the Committee, to acknowledge their great indebtedness not only to the Iron and Steel Institute but also to the British Iron and Steel Federation for the funds which had been provided. The corrosion research was now costing over £2,000 a year, and that meant that during the last four or five years the Committee had spent over £10,000 in endeavouring to solve in a systematic manner many of the problems with which the members of the Institute were concerned.

He would like to record a conversation which had taken place that morning between a very distinguished member of the Institute and himself. That member had asked him what the Corrosion Committee was and what its work amounted to. He replied: "As one of the great manufacturers of ship plates, you will be interested to know that it is pretty clear that if a ship corrodes

it is not the fault of the ship plates." The distinguished manufacturer in question said: "We have been telling people that for years," to which he (Dr. Hatfield) replied: "Yes, but having read the Report they will now believe it!"

That might be regarded in a sense as hardly a positive contribution to the subject; nevertheless, one of the very valuable aspects of the work of the Committee was the elimination of variables, the elimination of impressions and the confirmation of facts, apart from the very constructive work which would be disclosed by the Report now to be discussed.

The various sections of the Report were then briefly outlined by the individual authors.

Mr. T. Henry Turner (L.N.E.R., Doncaster) said that he would like at the commencement to say that he much appreciated the way in which the Committee had introduced its Report by a summary index; it had been a great help to him, in referring from page to page, to be able to turn to that summary.

From the point of view of the user, he thought one could not be satisfied with the statement that a ship would not corrode on account of the steel. The engineer did not want to depend on paint; for one thing paint hid defects which might be underneath. It was not only the cost of repainting which had to be considered. The Committee were apparently quite satisfied that the paint had stood for four years, but it was possible that in less than four years some crack might be developed underneath, which the paint would hide. The aim must still be to get something better which did not require painting at all, though perhaps another industry would dislike that when it was achieved.

With regard to pickling, it was interesting to see the choice made of the particular pickling process. From his point of view, he would like the proprietary restrainer to be mentioned by name or an analysis of it given.

It was very interesting to see how acid all the natural rain waters were. Industrial atmospheres were producing pH values of 4 to 6. He would regard anything under about 11 as being likely to cause corrosion in a boiler. All the ordinary waters obtained from bores and nearly all river waters would give a figure of 7 and upwards, that was, the natural water taken from a bore or from a river was definitely alkaline. One would increase its alkalinity to feel safe with a boiler; yet the figures given were very appreciably below that level and were in the acid range, so that in those areas there was a definitely corrosive atmosphere of an acid nature. That was more so still in a tunnel. Although a rail out in the open might last as long as a man's life—so far as records went, in a good open atmosphere a rail might actually last as long as a human being—in a tunnel it might last only three years.

There, of course, one had the condition referred to in the very interesting note in the Report on corrosion depending on humidity in mines. In the tunnel one had both the acid and the humidity causing an extraordinary reduction in the life of rails.

He had been coupling the work done at Woolwich with what Dr. Evans referred to in the following way. Dr. Evans had confirmed that partly scale-covered surfaces fared much worse than wholly scale-covered surfaces or surfaces completely descaled by weathering. The problem was how much one ought to spend on thoroughly cleaning a steel. If a bridge wanted patching and it was nicely covered with scale and the old paint looked in good condition, the bridge was merely given another dose of paint on the top, but if those conditions were not present the question arose of how much cleaning one could do on a scaffolding with the risk of a man losing his life if the scaffold gave way and with the chance of rain coming on during the operation, and so on. How far could one go with wire-brushing, chipping and so on, to gain complete freedom from scale ? Looking back to tests done at Woolwich on corrosion after different methods of cleaning, he noticed a very surprising difference between sand-blast and shot-blast. Going down the series, one would see that the resistance to corrosion seemed to depend on the consolidating effect on the surface (Appendix A, Section B), and those who had studied Table XVIII. carefully would see that the loss was least with finishes which gave what he called a consolidated surface. It was surprising that sand-blasting and shot-blasting should be so different in their effects ; perhaps the sharp indentations were giving a surface which was very much more easily attacked. The suggestion would therefore be that, since sand-blasting of structures in the open before painting had been practised and had become more economical in recent years, it would pay to replace sand by shot and try shot-blasting the outside surfaces, where such an operation was possible, before painting.

Mr. E. J. George (Member of Council, Consett) said he did not know whether it was quite fair of Dr. Hatfield first of all to refer to him as a distinguished member of the steel trade and then to quote his remarks. It was, of course, a matter of great interest to the ordinary steelmaker how far the expenditure upon research was warranted by its results, and one of the things which the research worker required to cultivate, as far as in him lay, was the ability to lessen his mystery and increase his clarity, to speak not in abbreviations and scientific terms only, but to speak with a recognition of the ignorance and want of understanding of the mere steelmaker and consumer. He would congratulate the learned gentlemen who had spoken that morning on the contribu-

tion they had made in the direction which he indicated. They had endeavoured to make clear the results of their work.

Dr. P. LEWIS-DALE (London) said that what struck one about the Report, as compared with some of the spasmodic previous attempts, was the really serious effort to put the investigation on scientific lines, so that the experimental results could be compared with one another under given conditions of test and their relation to corrosion in service conditions established on a satisfactory basis; any criticism, therefore, which he had to make would be in the direction of ensuring that the tests should be scientific and also should afford fair comparisons.

He had intended to refer to a point which Mr. Turner had already mentioned, namely, the inhibitor. He did deplore the use of a proprietary restrainer; he thought it should have been possible to use one which was not a proprietary product, so that, when one turned to the Report in years to come in order to repeat the same descaling process exactly, one would be provided with precise information. He did not think it would be very desirable, however, to give the name of the proprietary inhibitor, and very probably it would be no use doing so, since its composition might change in the course of a year.

Another point which he desired to mention was that, judging from Part 3 of Section B, there appeared to have been an extraordinary change in the water at Woolwich, the *p*H value going up from a little over 4 to 5·5. He mentioned that particularly because a comparison was drawn in the Report between the water at Woolwich, taken as 5·5, and the water at Sheffield, which was just over 4. In previous years at Woolwich the water had had a *p*H value somewhere in the neighbourhood of 4·3, but there had been a great change in the past year, and the value was now given as 5·5. There was a great change in the average total solids and so on, and he thought it would have been an improvement if the detailed figures for Woolwich could have been given, as had been done, he thought, in the previous Report for one full year at Woolwich. That would have enabled one to see what the variations in the water were, and whether it was a case of 4·6 for three samples or for half a year and then something like 6·7 or 7·8, which would presumably have altered greatly the results obtained on the specimens.

On p. 58 the statement was made: "... the service life of a wooden sleeper in a tunnel was stated to be of the order of six years ..." He thought it should be possible to find what was the average life of a sleeper in any particular tunnel. The steel sleeper experiments had been conducted, he believed, in a *particular* tunnel, and yet the statement was made that the service life of a wooden sleeper in *a* tunnel was six years. If that meant

the average life of a wooden sleeper in *a* tunnel, speaking generally, he thought the estimate was decidedly low.

Dr. HUDSON, interposing, said that there was a mistake in the wording, which should read : " Since the average life of a wooden sleeper in *the* tunnel." The figure of six years was given to him by the divisional engineer in whose area the tunnel in question was situated.

Dr. LEWIS-DALE said that the words " the tunnel " would make the point quite clear.

Another criticism which he had to make referred to p. 96, where it was stated : " It would appear from this analysis that the steel was made by the basic open-hearth process "—he did not quarrel with that—" the sulphur and phosphorus are on the high side." He thought most people would agree with him that that was rather an understatement when for the basic process one obtained phosphorus 0·054 per cent. and sulphur 0·070 per cent. ; he thought that was very decidedly on the high side.

There was a further point he wished to make with regard to the necessity, since the work was scientific, of specifying as nearly as possible what was actually meant in every instance. Reference was made in the Report to " 0," to " 00," and to " French " emery finish. He had lately been concerned with some tests on emeries, and, while he would not say that 0 emery could be coarser than No. 1, No. 1 emery could be coarser than No. 2, according to where it came from ; it might contain some coarser particles. It would be well worth while specifying that a little more closely, if possible.

With regard to the general conclusion that the protective scale was very important, he recalled one inspection which he had had the opportunity of making of the original scale on the tubular bridge over the Menai Straits. It had been in a remarkably good condition five years ago.

Dr. L. C. BANNISTER (Birmingham) wished to congratulate Dr. Bengough and Dr. Wormwell on the excellent standard of their work ; he thought they had attained a degree of reproducibility which had rarely if ever been attained before in corrosion research, and that called for nothing but the highest commendation. He noticed, however, among the results obtained by the accelerated test which they proposed should be used by industrial laboratories as far as possible, in which the specimen was allowed to corrode under a liquid above which was an atmosphere of oxygen, that more corrosion had been observed in Teddington tap water than in sea water, Fig. 33. That was observed not only by weight-loss determinations, but also by the degree of penetra-

tion which was found. The result was perhaps not so remarkable as it might at first appear to be, because he thought that under the conditions of the experiment the supply of dissolved oxygen would be greater in the Teddington tap water than in the sea-water, and that would probably account for the results which were obtained, but he thought that such an occurrence would be very rare under practical conditions; otherwise one would expect the users of domestic water in the Teddington district to have severe troubles comparable with those well known in the case of the condenser tubes on ships, but he had not yet heard of any committee being set up to investigate the corrosion caused by domestic water in any district, in the same way that a Committee had been set up to deal with the corrosion caused by sea-water. He thought it was rather a pity, therefore, if the standardised acceleration test which was proposed was based on such exceptional conditions.

In the section on the effect of substituting laboratory air for purified air it was stated that oxygen could not be used for accelerating the corrosion except under conditions in which rather high salt concentrations were used, so it appeared that another disadvantage was that the proposed test was not applicable to every solution for attaining the degree of acceleration which was required to bring the time limit of corrosion tests down to a reasonable figure. He thought a much simpler and possibly more logical way for bringing about that degree of acceleration which was so urgently required by industrialists would be found by considering Fig. 19 of the Report. In that particular diagram the authors plotted the rate of corrosion against the depth of immersion, and showed in a very interesting manner that when the top of the specimen was less than 1·5 cm. from the surface of the liquid the corrosion increased considerably, and they obtained points which lay very nicely on that curve. They showed that the depth, when greater than 1·5 cm., did not seem to make very much difference to the corrosion rate, and therefore they chose a standard depth on the horizontal part of that line to carry out their tests, because otherwise a very slight difference in the depth of immersion would make a very big difference in the rate of corrosion and so affect the accuracy of the results. One suggestion he would make was that the curve should be extended a little further by experiments in which the specimen actually projected through the waterline. The inaccuracy due to the difficulty of adjusting the specimen could be avoided if the specimen were allowed to protrude right through the surface of the liquid. The suggested extension, indicated by dotted lines in Fig. A, would appear to provide a method of accelerating the corrosion rate to about seven times that obtained at the standard depth of 1·5 cm. He referred in what he said to vertical specimens,

as he understood that Fig. 19 applied both to horizontal and to vertical specimens.

He noticed from Table XXXI. that when steel and zinc were tested in a certain chloride solution their order was reversed when a waterline was used as compared with the case when they were wholly immersed, so that, if by using a waterline the authors reversed the order of the corrodibility for those two metals, the

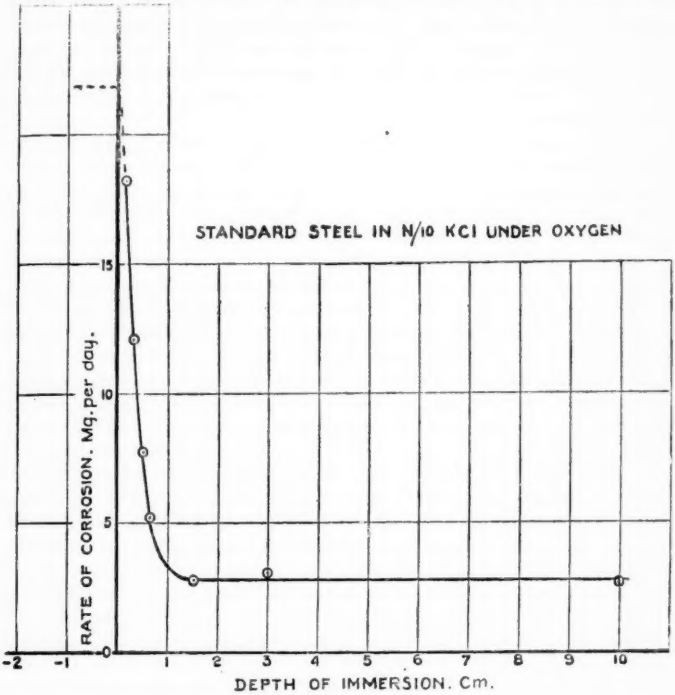

FIG. A.

order might also be reversed in the case of the Teddington water and sea water if a waterline were used instead of the conditions actually obtaining. He himself, and he thought others as well, would be very grateful if Dr. Bengough would state what objections there were to using a waterline whilst maintaining the other conditions of his tests.

Mr. M. A. W. BROWN (Wallsend) said his remarks would refer chiefly to Section C of the Report, dealing with marine

corrosion, and to some of those parts of Section D which had a direct bearing on the subject.

In the first place, it was to be noticed that it was stated in the Report that the major portion of marine corrosion was observed to have been solely due, in the case of the barge *Cactus*, to mechanical damage. That, he thought, was a difficulty met with not only in regard to the *Cactus*, but almost generally with the *outside surfaces* of ships' hulls. He thought he might again suggest, as he had done the previous year, that the insides of, say, tankers, which were exposed to ballast sea-water, &c., intermittently, might with profit be examined, inasmuch as the chance of mechanical damage was comparatively slight under those conditions.

With regard to the conditions of plates before painting, he thought that the findings of the Committee on the scaled *versus* descaled conditions would be welcome, and particularly so with regard to the probable ease of weathering off a scale produced by reduced finishing rolling temperatures.

With regard to the assembly stage of the plates of the *Cactus*, he asked if all the rivets were of the composition and mechanical properties given on p. 81 for a rivet, or whether that was just a random rivet or an average of a number, because batches of rivets were known to be extremely erratic in composition unless considerable attention was paid to the making of the rivets from the same rod right through from the very first stages of manufacture. He would also like to know whether the fuel of the heater's fire used was coal or coke, and whether it was relatively sulphur-free or otherwise. No information was given on such points, and it seemed to him from the Report of Dr. Mears (p. 111) that such questions should be seriously considered, especially in view of the corrosion probability effect of iron sulphide impurities in the surface layers of the finished job.

With regard to the actual painting, ships' painters commonly talked of two classes of paints, one the paint proper, the oil paint, where the medium was linseed or some similar oil, and the other composition, where the medium was naphtha or some similar spirit. It was further suggested that composite jobs—of paint *and* composition—were never so satisfactory as a *wholly* painted job or as a *wholly* compositioned job. It was frequently said that the composition and the paint did not harmonise, in fact, that they "fought." He thought that the reference in the Report to the diffusion of the black bituminous composition into either red lead or red oxide (probably producing an inefficient coating and probably initiating corrosion) might be taken as some evidence of at any rate a mild "fight" of that nature. He had had occasion a year or two ago to look into that question in a practical way, and he did find some justification for the view

that such " fighting " took place, chiefly on account of the fact that the oil paints " dried " by oxidation and *expansion*, whereas compositions dried by volatilisation and *shrinkage*. He thought that the Committee should definitely carry out some tests, at least on the paints they were using themselves, with a view to establishing some information upon those points.

He asked whether by any chance any ordinary chalk marks were made on any of the plates used and whether they had been since observed. Under conditions of long service he had often noticed chalk marks left on the outside of a ship's hull, which rather indicated that certain calcium pigments might profitably be employed in paints.

The use of a blowlamp (p. 88) for warming up the ship's hull, &c., during painting seemed a drastic or at any rate a hit-and-miss method of drying the plating. He thought the blowlamp might profitably be turned on to an air-blast pipe with a metallic end, so that, by using hot air only, there would be no chance of burning or charring the paint.

In conclusion, he would like to say that the Admiralty welding tests were of general interest but lost a good deal of their practical value to those interested in welding on account of the lack of data with regard to the electrodes used. That might be to some extent unavoidable, but he thought that a good deal of information which would have been welcomed very strongly had not been given. Encouraging results had been obtained, however, inasmuch as the Committee felt that corrosion troubles were not likely to be aggravated by welding, and that, *despite* the fact that relatively poor welding had been examined by them—as illustrated by the X-ray and mechanical tests made. He felt that the Committee should do more work on that subject, and he thought it would be a pity if further investigations on welding materials were dropped, especially in view of the increasing importance of the application of electric welding to shipbuilding nowadays.

CORRESPONDENCE.

Dr. G. D. Bengough and Dr. F. Wormwell (Teddington), referring to Dr. Mears' section on the " probability of corrosion " as determined at Cambridge, wrote that it seemed desirable to emphasise that it was characteristic of steel in highly specialised conditions only, and was not an inherent property of the steel itself, independent of those special conditions which included the use of a very small specimen (3 mm. square), very shallow layers of the corroding liquid in the form of drops, an atmosphere saturated with water vapour, short experimental periods (usually 22 hr.),

and relatively smooth surfaces. Some of the most striking results had been obtained in a carefully chosen solution of $NaHCO_3$; a strong solution of that salt would reduce the "probability" of ordinary steels to zero; in fact, the concentration greatly affected the "probability."

When steels similar to some of those used in the research were used as turned specimens several square centimetres in size, placed at a depth greater than a few millimetres in sodium chloride solutions or industrial waters, the probability rose to 100 per cent. and could be neglected. The "probability" as determined by the drop method was, in fact, characteristic of the special physical and chemical conditions of the metal-liquid-gas system used, and not solely of the metal; no deductions from it could be made as to the probability in other conditions—for instance, at greater depths of immersion—even when similar metal was used.

On p. 111 Dr. Mears suggested that the probability as determined by the drop method had "practical significance," yet on p. 112 he stated that he and other Cambridge workers "avoided conditions which would cause nearly all the drops to corrode," that was, they carefully chose conditions which specially emphasised variations in probability, and, in particular, used extremely small specimens. That seemed greatly to limit the "practical significance," which appeared to be confined to some kinds of atmospheric attack at very small holes through protective layers of paints, &c.; with holes only a few square centimetres in area the probability would approximate to 100 per cent. and possess little significance.

It also seemed clear that before the "practical significance" of the probability results could be assessed their relation to the rate of penetration should be investigated; the short time of the experiments, which appeared to have been usually 22 hr., hardly seemed suitable for the establishment of such a relation. At present there did not appear to be any real evidence for such a statement as "the distribution of the sulphide present in the surface layer itself may have an influence on the service rendered by the material." No experiments seemed to have been made yet on the question of the cessation of action at the initial starting points by such processes as "stifling," and the question arose whether the results of the method were more dependent upon the nature of the particular type of metal surface used than upon the amount of minor constituents present or the method of manufacture.

The writers would be interested to know what kind of service conditions the author believed his drop tests to represent?

Dr. U. R. Evans (Cambridge University) wrote that the paper by Dr. Bengough and Dr. Wormwell represented a large

number of careful measurements, the accuracy of which would be admired even by those who challenged the interpretation. He was genuinely sorry to be compelled to state the view that the testing method suggested would have somewhat limited utility.

The method severely rationed the specimen with oxygen. If pure iron could use up all the oxygen reaching it, impure iron could corrode no faster, provided that the impurities did not increase the rate of rationing or dispense with the need for oxygen. If iron was replaced by zinc, which had a different type of corrosion-product and would therefore alter the rate of rationing, or by magnesium, which could corrode readily in the complete absence of oxygen, the velocity of corrosion was altered; again, if, retaining iron as the metal, a sodium chloride solution was replaced by ammonium chloride (where the increased hydrogen-evolution would stir up the liquid, increasing the oxygen supply) or by citrate (which prevented the formation of rust, as the authors pointed out, and probably provided an efficient and highly soluble oxygen-carrier), then alteration of the corrosion-rate would be, and was, obtained. But if merely small amounts of carbon, manganese or sulphur were introduced into the iron, it was unlikely that the rate of rationing of oxygen would be greatly affected, and accordingly the authors' curves were in some cases hardly altered thereby. And yet under circumstances of plentiful aeration, ferrous materials of different purities were corroded at different rates; under some conditions—not under all—sulphur was a special danger.

The difference between the corrosion-rates of different grades of iron and steel had been found in seven researches by four different experimenters at Cambridge. Those include conditions where the specimens were half-immersed,[1] intermittently sprayed,[2] corroded by drops,[3] shaken in tubes containing aerated liquid,[4] or exposed to the atmosphere.[5] The differences had been established by tests, carried out in multiple so as to render the "probable error" small, even in those cases where the scatter was large. Similar differences had been found in other laboratories; moreover, the atmospheric tests of the American Society for Testing Materials, as well as spray tests conducted for the Iron and

[1] S. C. Britton and U. R. Evans, *Transactions of the Electrochemical Society*, 1932, vol. 61, p. 450. U. R. Evans and T. P. Hoar, *Proceedings of the Royal Society*, 1932, A. vol. 137, p. 351.

[2] U. R. Evans and S. C. Britton, *First Report of the Corrosion Committee*, 1931, p. 139.

[3] R. B. Mears and U. R. Evans, *Transactions of the Faraday Society*, 1935, vol. 31, p. 531.

[4] K. G. Lewis and U. R. Evans, *Journal of the Society of Chemical Industry*, 1934, vol. 53, p. 25T.

[5] S. C. Britton and U. R. Evans, *Journal of the Society of Chemical Industry*, 1932, vol. 51, p. 211T. K. G. Lewis and U. R. Evans, *Third Report of the Corrosion Committee*, 1935, p. 177.

Steel Institute Corrosion Committee by Hudson, by Hatfield and Shirley, and by Schroeder, showed up marked differences between different grades of ferrous metals ; the reality of those differences was not in doubt.

The authors considered, however, that in their method sufficient oxygen reached the metal, the mode of transport depending, in their opinion, on *unintended* thermal convection currents. In effect their claim seemed to be that the imperfections of the thermostat had saved the situation. He (Dr. Evans) felt very doubtful, however, whether the thermal stirring was as vigorous as the authors thought. He did not deny that in the early stages of this research—when it was desired to *avoid* thermal convection currents—he himself had felt[1] misgivings about the use of luminous heaters. If a Beckmann thermometer received heat on one side only by radiation, losing it at the same rate on the other side, it would show a nearly constant reading (the Beckmann thermometer appeared to be somewhat unsuited for rapid fluctuations of temperature, owing to its large heat capacity). If the experimental vessel, or specimen, similarly received heat and lost heat at the same rate, although its mean temperature would remain constant, there would be convection currents of just the kind which—in most work—it was desired to avoid. Nevertheless he found it a little difficult to think that the whole oxygen supply to the metal was provided in that way. Mears had calculated that a temperature fluctuation even as great as 1° C. would only produce a density change of about 0·025 per cent., whereas Bengough's rust-sludge, containing 1 in 173·5 parts of ferric oxide, would increase the density of the liquid by about 2·4 per cent., namely, 96 times as much. It was, however, satisfactory to note that the authors' measurements of ferric oxide in sludge fell within the limits of his own measurements for rust settled in different liquids for different periods.[2]

It might perhaps be argued that half-immersed specimens were also rationed with oxygen, since only the meniscus zone was freely aerated. Here, however, small differences in the metal itself determined the rate of oxygen utilisation. Steel would usually contain, within the meniscus zone, more cathodically active points than pure iron, and consequently could use up more oxygen as a depolariser ; hence, steel corroded more quickly, under these conditions, than pure iron.[3] In other words, a partial immersion test showed up small differences between materials, which a total-immersion test, under stagnant conditions, did not.

[1] U. R. Evans, *Transactions of the Faraday Society*, 1931, vol. 27, p. 577.
[2] U. R. Evans, *Journal of the Society of Chemical Industry*, 1928, vol. 47, p. 55T.
[3] U. R. Evans and T. P. Hoar, *Proceedings of the Royal Society*, 1932, A. vol. 137, p. 350.

In applying the oxygen-absorption method to iron, it was necessary to know the proportion of ferrous and ferric compounds in the corrosion product. That ought to be determined, for any given material and liquid, after several different periods, which data *alone* would provide a corrosion-time curve, making measurements of oxygen-disappearance unnecessary.

Another objection to the oxygen-absorption method had become apparent in recent work. If the liquid was originally saturated with oxygen, the *corrosion rate* would usually be faster than that of a similar liquid not saturated with oxygen, as the authors themselves believed. The proposed method, however, actually measured the *disappearance* of oxygen from the gas-space, which in the case of liquid originally saturated with oxygen was likely to be *slower* than for liquid not originally saturated. Mears had found, experimentally, in an apparatus rather like that of the authors, that the rate of oxygen disappearance in an experiment started with a liquid of *high* initial oxygen concentration was *less* rapid than that when the original liquid was almost free from oxygen, although doubtless the corrosion rate was greater in the first case. For comparing the corrosive action of liquids under conditions of changing oxygen content, the oxygen-absorption method in this form was not only inaccurate, but might point in the wrong direction ; this criticism did not apply to the forms of oxygen-absorption method used by Whitman, Speller, Forrest and others. Apparently the authors admitted the limitation, since it was understood that their curves showing the early stages of corrosion,[1] although expressed on the diagram in terms of oxygen absorbed, were actually obtained by a loss of weight method.

Another objection to the oxygen-absorption method was the time-lag between the moment of absorption of oxygen at the liquid surface and its arrival at the metal. That would not vitiate cases where the velocity was independent of time—and in such conditions it had been found at Cambridge that the method agreed with the weight-loss method.

The established fact that, at a non-corroding area of metal, the settling of rust from a corroding area greatly increased the chance of corrosion, was commonly attributed to " oxygen-screening " by the settled rust, which would tend to make the screened area anodic.[2] The authors[3] had denied that, holding that the forms of their corrosion-time curves were inconsistent

[1] G. D. Bengough and F. Wormwell, *Proceedings of the Royal Society*, 1933, A. vol. 140, p. 418.

[2] J. Aston, *Transactions of the American Electrochemical Society*, 1916, vol. 29, p. 458. Also R. J. McKay, *Industrial and Engineering Chemistry*, 1925, vol. 17, p. 23.

[3] G. D. Bengough and F. Wormwell, *Proceedings of the Royal Society*, 1933, A. vol. 140, p. 412.

with oxygen-screening by rust. Actually they stated that the early part of their curves was parabolic, indicating that the corrosion-rate was at first very fast[1] and gradually became slower. The usually accepted interpretation of a parabolic curve was that a layer of corrosion product was accumulating, which restricted the access of oxygen or other corrodent; Vernon,[2] for instance, had thus interpreted the parabolic curves obtained in his atmospheric researches. Bengough, however, had adopted a different explanation for his own parabolas, and this had caused Mears, at the sacrifice of other important work, to carry out an investigation into the passage of oxygen through different corrosion products. Mears[3] had found directly that settled corrosion products did obstruct the advance of oxygen down a tube. Bengough now stated that there was no analogy between Mears' observations and his own corrosion experiments, since his own rust consisted of very fine particles which even the very mild thermal convection currents present in his own vessels kept in suspension. If, now, Bengough's rust was of a completely different character from that which produced rusting where it settled on an iron surface, his curves could not possibly have any bearing on the mechanism of the production of rusting by settled rust. Mears naturally used settled rust in his work. He (Dr. Evans) felt that he must take the opportunity to make a friendly protest against the time repeatedly lost by his collaborators in testing criticisms which—coming from Dr. Bengough's laboratory—could not be disregarded, but which nevertheless turned out, on investigation, to be based on a very slender foundation.

He made this protest, not because he desired to give offence, but because the postponement or abandonment of really promising lines of work, which the examination of these criticisms had involved, had become one of the major obstacles to rapid progress in the Cambridge Laboratory.

Dr. T. P. Hoar (Cambridge University) wrote that, while associating himself with the views expressed by Dr. Evans and Dr. Mears, he would like to call attention to certain other aspects of the section written by Dr. Bengough and Dr. Wormwell.

It seemed to him a pity that in a paper embodying suggestions for a standardised corrosion test, no recommendation was made that electrochemical investigations should accompany the ordinary corrosion velocity tests. Measurements of electrode potential,

[1] Bengough and Wormwell stated that the initial corrosion rate was "infinite"; perhaps that was not meant to be taken literally; chemical considerations would preclude an infinite velocity.

[2] W. H. J. Vernon, *Transactions of the Faraday Society*, 1927, vol. 23, p. 124.

[3] U. R. Evans and R. B. Mears, *Proceedings of the Royal Society*, 1934, A. vol. 146, p. 157.

and, where possible, polarisation phenomena, often gave much more information as to the corrosion *mechanism* than did velocity tests, and a knowledge of its mechanism was of vital importance in the search for means of reducing corrosion. It was often argued that the technique and interpretation of electrochemical measurements were beyond the scope of the general laboratory of the "practical man." If that was indeed the case, it was the practical man who was at fault; and if he failed to make use of a new tool because greater skill was required in its handling, he might find that his products were becoming increasingly inferior to those of his competitors.

There appeared to be neither justification nor necessity for the authors' assumption of anodic films which hindered the flow of metal ions into the solution (p. 139). All the authors' statements with regard to cathodic and anodic potentials were made without any supporting electrochemical measurements. If they could show experimentally that the potential of the anodic parts of the corroding metal became considerably more noble with time, then the hypothesis of restrictive film formation at the anodes would command attention; in the absence of such evidence, it must be regarded as an unnecessary *ad hoc* assumption, because the facts it was used to explain could be accounted for equally well without it.

Thus, the anodic potential of a corroding metal depended on (1) the nature of the metal, (2) the nature of the electrolyte, (3) the current flowing, as well as on the presence or absence of an anodic film; the first two factors were quite sufficient to explain different corrosion rates when all other things were equal, as in the cases referred to at the top of p. 139.

Again, the distribution and velocity of the corrosion of iron in NH_4Cl was readily explained by the dissolution in this medium of the invisible *cathodic* film of hydrated ferric oxide, which, in NaCl, covered the areas not undergoing attack. That film required alkali to keep it in repair; in NH_4Cl, the small alkaline dissociation constant of NH_4OH, and the buffering action of the excess NH_4Cl, would prevent the formation of the necessary alkali at the cathodes; the film would be undermined and disappear, allowing general corrosion as found in dilute acids (p. 140). The much greater rate of hydrogen evolution in NH_4Cl might be due to (1) the larger film-free area, exposing more points catalytically active for the cathodic liberation of hydrogen, and (2) the lower *p*H of the solution near to the cathodes, due to the prevention, by the buffering action, of alkali formation. It might be agreed that the increased hydrogen evolution caused stirring and hence increased oxygen absorption.

Dr. R. B. Mears (Cambridge University) wrote that Dr.

Bengough and Dr. Wormwell deserved a large amount of credit for the great number of accurate measurements which made up the body of their paper. It was, perhaps, only natural that in a work of this magnitude several points should occur with which other investigators in this field were not in accord. Several such points of disagreement had already been mentioned by Dr. Evans and Dr. Hoar, and with them he was in general agreement. However, he would like to emphasise two further points.

Bengough and Wormwell apparently recommended their oxygen-absorption test for the use of industrial laboratories, presumably for the purpose of serving as a form of accelerated corrosion test. That would appear unwise since (1) it was doubtful if any single laboratory test would give trustworthy information as to the corrosion velocity of any certain material when exposed to a definite set of service conditions, and (2) the authors did not appear to have compared the corrosion velocities of their materials when subjected to their test with those which occurred when those materials were exposed to service conditions. As had been mentioned already by Dr. Bannister, the fact that they obtained higher corrosion velocities in Teddington tap water then in sea-water was certainly a strong indication that their apparatus did not simulate "practical" conditions.

The real value of laboratory tests would seem to lie in clarifying the mechanism of corrosion and in evaluating certain special properties of the material under consideration, such as, the susceptibility to intercrystalline attack, the tendency to localised or general attack, &c. Corrosion velocities obtained in a laboratory would almost certainly be different from those obtained on actual exposure, and even the relative corrosion rates for a series of materials were usually quite different in the two types of exposure.

In this form of complete immersion test, for relatively corrodible materials like iron and zinc, the measured corrosion velocity would depend largely on the rate of transfer of oxygen through the solution. This rate of transfer would be much different in the laboratory from what would generally obtain in practice, as in the sea, for example. Under their laboratory conditions, according to Bengough and Wormwell, imperfections in the means of temperature regulation must be depended upon to prevent the slow process of diffusion from being the main method of oxygen transfer. If those accidental temperature fluctuations were indeed the main cause of oxygen transfer, their method would appear to most unsatisfactory. Different thermostats could be expected to have different characteristics; presumably no two investigators working in different locations could be expected to obtain the same corrosion velocities for

the same materials. Further, the more carefully the investigator controlled his temperature, the more subject to " oxygen starvation " would his materials become. That was indeed a sad state of affairs !

Considering the great differences between the methods of testing used at Teddington and at Cambridge, it was not surprising that differences of opinion regarding the mechanism of corrosion had arisen. These differences had been so stressed, however, that the average reader might be inclined to believe that the two views were irreconcilable. Actually that was not the case, more especially for half-immersed specimens, but also to a less extent for specimens completely immersed. For example, in their last paper[1] on the subject of half-immersed specimens, Bengough and Wormwell listed nine conclusions ; the first seven appeared to be very similar to views previously expressed by Dr. Evans,[2] although they avoided one feature of his views, namely, oxygen screening. However, from their paper the ordinary reader would certainly infer that they were expressing an entirely new theory irreconcilable with the opinions of the Cambridge Laboratory.

For completely-immersed specimens there were also certain points on which, it was believed, agreement might exist. These could be expressed as follows :

(1) Settled, nearly solid masses of corrosion product interfered with oxygen transfer by lagging convection currents in the liquid, if in no other way.

(2) Corrosion products forming colloidal suspensions of low viscosity would not be expected to interfere greatly with oxygen transport.

(3) In cases where corrosion products fell through nearly stagnant liquid, stirring would ensue, and the rate of oxygen transport would be increased.

(4) In cases where gas bubbles were freely evolved during the corrosion process, oxygen transport through nearly stagnant liquids would be increased.

(5) Raising the oxygen concentration in the liquid might be expected to increase the velocity of corrosion, provided that corrosion occurred at all.

It was not the intention of the writer to minimise differences of opinion which did exist between workers in these two laboratories, but it was considered desirable to point out that there were considerable points of agreement.

Mr. H. W. Townshend (South Bank-on-Tees) wrote, with reference to marine corrosion, that deep local pitting which sometimes developed on mild-steel shell plates within a comparatively short time after a ship had been put into commission had

[1] G. D. Bengough and F. Wormwell, *Proceedings of the Royal Society*, 1933, A. vol. 140, p. 399, and especially pp. 407–409.

[2] U. R. Evans, *Proceedings of the Institution of Civil Engineers*, 1931–32, vol. 234, p. 460. U. R. Evans and T. P. Hoar, *Proceedings of the Royal Society*, 1932, A. vol. 137, pp. 346–347. U. R. Evans, *American Institute of Mining and Metallurgical Engineers*, 1929, *Technical Publication No.* 205, p. 16 : *Journal of the Society of Chemistry and Industry*, 1928, vol. 47, p. 57T.

caused shipowners, classification societies and shipbuilders a good deal of concern ; that pitting might occur only on an isolated plate or two, or it might be on several ; it usually developed rapidly within the first twelve months, and generally was less troublesome after that period.

An interesting case had recently developed on several small ships built during the past two years. Deep pitting had occurred in the after edges of the overlapped shell for about 30 ft. from the stem and 6 ft. up from the keel ; some of these boats had been dry-docked after two months in service, when there was already evidence of this trouble ; where four months had elapsed before docking the pitting was severe.

It had been suggested that the pitching action of these vessels in a seaway, due to which the forward end was repeatedly in and out of the sea, might have produced the conditions for this rapid corrosion.

It had been observed that plates from some mills appeared to be more subject to pitting than others.

Cleaning out the pitted portions and coating with gold size generally arrested this trouble.

In the paper recently given by Dr. Hatfield before the Institution of Naval Architects, entitled " The Corrosion Problems of the Naval Architect," and in the subsequent discussion, references were made to this type of corrosion. Mr. Robert F. Hand, in his paper on " Ocean Transportation of Petroleum in Bulk," read before the North-East Coast Institution of Engineers and Shipbuilders, in April, 1935, also made references to similar and other types of corrosion.

COMMITTEE'S REPLY.

Dr. W. H. HATFIELD, F.R.S., replying on behalf of the Committee, said that they very much appreciated the discussion which had taken place. Many of the detailed points raised must be replied to in writing.

Mr. Turner's remarks were very interesting, and the point he emphasised with regard to the apparent difference between the results of shot-blasting and sand-blasting was a good one, though too great weight should not be placed on the results obtained with these few trial specimens, more especially since they were exposed with only one side specially treated, the other still carrying the original rolling scale.

If he might be allowed to say so, he was very disappointed at Mr. George's contribution to the discussion, because the opportunity had been given to Mr. George to reinforce the Report with the experience which must be at his command in the way

of evidence in connection with ships. He sincerely hoped that in the quietness of Mr. George's own library at home he would feel able to add to what he had said, and, from the stock of information which he must possess, help to reinforce and make final and definite the conclusions which the Committee might almost be said to have come to with regard to corrosion.

The Committee very much appreciated the remarks made by Dr. Dale, Dr. Bannister and Mr. Brown. If Mr. Brown could facilitate the investigation of the interior of tankers he was sure the Committee would be glad to take advantage of any opportunities placed at their disposal.

With regard to Mr. Brown's remarks on rivets being somewhat erratic in composition, that, of course, was one of the main points with which the Corrosion Committee was trying to deal, to ensure consistency of quality and composition not only in ship plates but also in rivets.

With regard to welding and the reference which Mr. Brown made to the experiments at the Admiralty, he was sure that Mr. Meryon, to whom the Committee were indebted for the work, would be very glad indeed to place at Mr. Brown's disposal full information as to the electrodes employed.

In further reply on behalf of the Committee, Dr. Hatfield wrote that they would be very interested to have details of any cases of abnormal corrosion of ships such as those referred to by Mr. Townshend.

With regard to Mr. Turner's remarks on the question of the amount of cleaning which should be given to steel surfaces before painting, it was of interest to note that the Committee's tests to date indicated that there was a tendency to reproduce the same order of merit on repainting experimental stands as that observed after the first painting. It would appear to be very important, therefore, to ensure the best possible surface conditions before the first painting.

Dr. Dale was undoubtedly correct in indicating that a comparison of the acidity of the rain water collected at Sheffield and Woolwich, respectively, based on only one year's exposure in the latter case might prove misleading. Nevertheless the actual *p*H values for the four quarters during the last year at Woolwich were 5·5, 6·5, 5·7 and 4·3, respectively, so that the mean value 5·5, given in the table, might be considered as a reasonable one.

The point made by Dr. Dale concerning the fineness of various emeries was a good one and would be borne in mind by those members of the Committee more particularly concerned with tests of this type. The Committee would also bear in mind the desirability of using a restrainer of known composition in the derusting of the main series of test specimens. The tests

already carried out with the Woolwich specimens were exploratory only.

In reply to Mr. Brown's questions on the rivets used for the *Cactus*, it was, of course, the plates which the Committee had under particular observation, and the full history of the rivets was not known. It was understood, however, that they were from one delivery, and the sample used for the examination was taken at random from a batch collected during the actual riveting. The heating of these rivets was carried out in a coal fire.

As regards the observation of chalk marks on the plates of the *Cactus*, some of the paint marks on the original plates had been observed at subsequent inspections in service, but no definite instance of a chalk mark being preserved had been noted.

Reply to Correspondence on Section D, Part 2.

Dr. R. B. MEARS replied that Dr. Bengough and Dr. Wormwell seemed to be doubtful of the value of a standard method of scientific procedure, which consisted in studying the effects produced by the alteration of one variable at a time. They would appear to favour the more complicated procedure of altering several at once. In the present case, for instance, the initiation of corrosion was influenced by several different factors. These could be selected in any one of an infinite number of combinations, all of which might be encountered in " normal " exposures. If these factors were chosen so that in " blank " runs attack occurred at every drop, clearly an alteration of the variable under investigation could not cause a greater number of drops to corrode. In order to learn whether any variable could increase the fraction of drops causing attack, the blank conditions must be chosen so that an alteration produced by the variable under consideration could be detected.

Drs. Bengough and Wormwell appeared to think this test had little practical significance, since it was confined to " some kind of atmospheric attack at very small holes through protective layers of paint, &c." For ordinary irons or steels the significance was greatest for coated materials, since here also attack at one point had little effect on the corrosion at adjacent areas, but these coated materials formed a very large proportion of all the iron and steel that was used. For stainless steels and other metals, such as aluminium, the corrosion probability was of importance even for uncoated materials.

For coated metals, the corrosion probability might be more important than the corrosion velocity, since once corrosion was initiated, destruction of the coating in the vicinity of the attacked area followed; the fact that this destruction occurred in one week instead of in one month was surely less important than whether

or not corrosion commenced at all. For exposed iron areas as great as 9 sq. mm., corrosion did not occur in every case, even under relatively "corrosive" conditions such as exposure to potassium-chloride/hydrochloric-acid mixtures with a *p*H value as low as 3·8. Smaller exposed areas corroded still less frequently, and the areas exposed by microscopic pores in a coating would be expected to cause attack very rarely indeed under these conditions.

With regard to the criticism that the short period of exposure (22 hr.) was unsuitable, earlier investigations had shown that the number of drops causing attack was independent of the duration of the period of exposure from 15 min. up to 32 days—at least, provided that none of the conditions of the experiment were altered during that period. Since this was the case, the selection of the length of exposure could be based on convenience. For periods less than 12 hr. it was more difficult to measure the extent of corrosion. The period employed was quite satisfactory in this respect. In any event, long periods of exposure in laboratory corrosion work were of very questionable value, since the accumulation of corrosion products undoubtedly modified the results by introducing another variable. The extent of this modification depended on the nature of the products formed under the particular conditions of the experiment.

The author had a great distrust of synthetic "service tests," and did not consider that this drop test was strictly analogous to any kind of actual service conditions. Neither, for that matter, were any of the methods for accelerated testing, including Drs. Bengough and Wormwell's complete-immersion test. Whatever value there was in the drop test lay in the fact that by employing it one could measure the effect of variations in any given factor on both the corrosion probability (susceptibility to attack) and on the velocity of corrosion once attack had commenced (conditional velocity). The division of the average velocity into its two components was considered very important, since an alteration in external environment might change these in different directions, making very difficult an interpretation of the changing value of their product (the average velocity), unless the two variables were separately measured.

Reply to Discussion and Correspondence on Section D, Part 3.

Dr. G. D. Bengough and Dr. F. Wormwell wrote, in reply to Dr. Bannister, that they appreciated his kind remarks on their technique. They did not, however, suggest, as Dr. Bannister appeared to think, that the standard test discussed in the paper was in any way universally applicable (*see* p. 128). It was one type of test which had definite uses, but it was emphasised on

p. 125 that for practical purposes a whole series of standard tests, each representing a definite type of condition, was necessary. All they claimed was that the test described afforded an accurate basis for the suggested system of tests.

The greater rate of corrosion in tap water than in sea water could not be attributed solely to the differences in the oxygen solubility in the two solutions. This was shown clearly in Table A, in which the values for "tap water (calc.)" and "sea water (calc.)" were calculated from the oxygen absorption rate in $N/2$ NaCl on the assumption that in each solution the oxygen absorption rate was directly proportional to the oxygen solubility in that solution. It would be seen that the calculated corrosion rate in sea water (8·40) was greater than in $N/2$ NaCl (7·68), although the oxygen solubility had been taken as the same in the two solutions. This was because hydrogen evolution was responsible for more corrosion (1·07 mg. per day) in sea water than in $N/2$ NaCl (0·29 mg. per day).

TABLE A.—*Comparison Between Corrosion Rates and Oxygen Solubilities.*

	$N/2$ NaCl.	Tap Water.		Sea Water.	
		Calc.	Obs.	Calc.	Obs.
Oxygen absorption rate. Ml. per day	2·34	2·75	2·44	2·34	1·45
Hydrogen evolution rate. Ml. per day	0·125	..	0·083	..	0·47
Rate of corrosion due to hydrogen evolution. Mg. per day	0·29	..	0·19	..	1·07
Total corrosion rate. Mg. per day	7·68	9·30	7·8	8·40	4·70

The relation between the corrosion rates of tap water and sea water in "practical conditions" would depend on the exact nature of the conditions. Friend[1] had already shown that in open vessels containing fairly stagnant solutions, tap water caused more rapid corrosion than an artificial sea water, really a 3 per cent. salt solution. In moving tap water, however, the corrosion rate first fell and then rose with the speed and time, while that in $N/2$ NaCl and sea water rose; at relatively low rates of movement, the corrosion was greater in the chloride solutions; such facts as this supported the authors' contention that no one type of test was sufficient to define either the absolute or the relative rates at which metals would corrode.

[1] J. Newton Friend, *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1922, vol. 11, p. 154; 1923, vol. 12, pp. 10, 16.

Dr. Bannister commented on the possibility that oxygen could only be used in the authors' tests to accelerate corrosion in solutions of "rather high salt concentrations." The range was actually from $N/1000$ to $N/10$; that was a very useful range, embracing many types of industrially important fresh waters. It could be extended to include sea water by introducing a more complicated calculation.

Concerning Dr. Bannister's suggestion for using half-immersed specimens, that was quite impossible, because the corrosion/time curves were of different shapes. It was true that Evans and Hoar,[1] on the basis of results obtained for a maximum period of four days, stated that the curve for partially-immersed mild steel was linear, but the authors' experiments, continued for much longer times, showed clearly that there was a continuous fall in the corrosion rate.[2] This had lately been found (unpublished work) to be due to the accumulation over the anodes of products physically quite unlike those formed in totally-immersed conditions. It was thus impossible to argue from one type of test to the other.

From some points of view it was not justifiable to extrapolate the curve of Fig. 19 to almost zero depth. There were changes in the corrosion distribution when a zone extending from the waterline to a depth of a few millimetres was reached. Thus, though the rate of total corrosion would be given correctly, the rate of penetration would not. With a specimen actually protruding above the surface the experimental facts were again different, as already stated. The results given in Fig. 19 were obtained with horizontal specimens.

There appeared to have been a misunderstanding about Table XXXI. On p. 145 the authors stated: "The corrosion rates increase with alteration of the experimental conditions from the top of Table XXXI. downwards." The meaning was that the rates were least in 4·4-cm. vessels with total immersion, intermediate in 9·4-cm. vessels, and greatest with partial immersion in 4·4-cm. vessels. In the column "different rates," the order of writing down the different metals had no significance. Thus, at the bottom "steel *FS*, zinc" did *not* mean that steel corroded more rapidly than zinc. Zinc corroded more rapidly than steel in both partially- and wholly-immersed conditions. Actually, in the authors' experiments the *difference* between the rates for the two metals was greatest in conditions of total immersion at 1·5 cm. in $N/10$ KCl under oxygen in 4·4-cm. vessels, and less when partially immersed in the same solution

[1] U. R. Evans and T. P. Hoar, *Proceedings of the Royal Society*, 1932, A. vol 137, p. 349.

[2] G. D. Bengough and F. Wormwell, *Proceedings of the Royal Society*, 1933, A. vol. 140, p. 404.

under oxygen in similar vessels. That was shown in the following Table B, which gave the ratios of the rates in several different conditions.

TABLE B.—*Ratio of the Corrosion Rates of Zinc and Steel in* N/10 *KCl under Oxygen.*

Conditions.	Ratio : $\frac{\text{Corrosion rate of zinc}}{\text{Corrosion rate of steel}}$
4·4-cm. vessel, immersed at depth of 1·5 cm.	2·62
9·4-cm. vessel " " " "	2·17
4·4-cm. vessel, " " " 0·35 mm.	1·30
Partial immersion	1·85
4·4-cm. vessel at 3 atm. pressure and depth of 1·5 cm.	2·1

The suggestion that in partially-immersed conditions sea water might be more corrosive than tap water was disproved by the results given in Table C. The specimens were in the form

TABLE C.—*Loss of Weight of Partially-Immersed Specimens.*

N/2 NaCl	1·3195 grm.	in 226 days.
Sea water	0·5822 grm.	
Tap water	0·5951 grm.	

of milled strips of the standard *FS* steel, 5·0 cm. by 2·0 cm. by 0·4 cm., suspended with 3·0 cm. immersed. The vessels were placed on the laboratory bench under a draught shield, and the water-line was deliberately allowed to vary between 3·0 and 3·5 cm. from the bottom of the specimen. It was noteworthy that with partial immersion the corrosion rate in the tap water was about the same as in sea water but less than in *N*/2 NaCl, but it was clear that the different relative corrosion rates shown in Tables A and C were due not solely to different rates of oxygen supply, but also to different methods of immersion.

It was surprising to find Dr. Evans still persisting in the view that the authors' method of testing was of "limited utility," in that it "severely rationed the specimen with oxygen." In all corrosion experiments, field tests, and industrial usage, the oxygen supply to metals totally immersed in stagnant or slowly-moving water was rationed, and this condition was therefore not peculiar to the authors' tests. The authors had shown that the "rationing" in their tests was quite liberal, and far greater than in the normal type of test in open beakers, and even allowed

corrosion rates greater than those observed in Friend's field tests in docks, harbours, and the open sea. The authors had repeatedly called Dr. Evans' attention to this but without effect.[1] Dr. Evans used his "rationing" argument five years ago and predicted that the authors' method would give the same oxygen absorption rates for zinc, iron and steel. In 1931 this was shown to be wrong,[2] since zinc gave much higher rates than steel. Subsequent work showed that steel and iron could not make use of the whole of the oxygen supply in the standard conditions, so that Dr. Evans' argument "If pure iron could use up all the oxygen reaching it, impure iron could corrode no faster. . . " was irrelevant. The authors' view could be summarised by saying that though any conceivable test was of "limited utility," nevertheless their test was useful over a relatively wide range of industrial conditions of total immersion.

Dr. Evans attempted to explain the different corrosion rates of zinc and iron by attributing them to different degrees of circulation of the solutions caused by the falling corrosion products. This the authors regarded as definitely wrong, and they had given several reasons for their view in the paper (pp. 134–136). No satisfactory reply to some of the reasons had ever been forthcoming from Dr. Evans or from his associates Dr. Mears and Dr. Hoar, who stated that they shared his view, but if they required additional evidence it was to be found in the following facts: (1) The difference in corrosion rates between zinc and iron was not confined to deeply-immersed specimens, when the oxygen supply was mainly by convection and might possibly be affected by falling corrosion products, but it persisted into the zone of shallow immersion, where the oxygen supply was almost entirely by diffusion to the upper surface of the specimen and would not be affected by corrosion products falling from the lower surface. (2) The rate of corrosion of mild steel under 5 atm. pressure of oxygen was five times that at 1 atm.; owing to the rapid rate of production and falling of the corrosion products the rate should be greater than five times if this falling contributed an appreciable proportion of the total oxygen supply. Since so many different types of experimental corrosion results all pointed to the negligible effect of the falling corrosion products, the authors regarded this matter as no longer open to dispute, whatever results might be obtained in conditions which were merely assumed by Dr. Evans to represent corrosion experiments.

The reason for the different and higher corrosion rate of magnesium as compared with zinc and steel was certainly, as Whitby[3]

[1] For instance, p. 144 of this paper, and *Chemistry and Industry*, 1933, vol. 52, p. 230, Table IX.

[2] G. D. Bengough, A. R. Lee and F. Wormwell, *Proceedings of the Royal Society*, 1931, A. vol. 131, p. 494.

[3] L. Whitby, *Transactions of the Faraday Society*, 1932, vol. 28, p. 476.

first showed at Teddington, due to the large hydrogen evolution which corresponded to the whole of the corrosion, oxygen taking no part. It was satisfactory that Dr. Evans accepted the experimental demonstration that the high rate of corrosion of steel in $N/2$ NH_4Cl was largely due to the high rate of hydrogen evolution. In sodium citrate, it was possible that Dr. Evans' view that the citrate acted as an oxygen carrier was correct, though there was no direct evidence for it at present, and it was certain that a large proportion of it did not so act.

The quite untenable argument was used by Dr. Evans in the second and third paragraphs of his communication that because he and some other authors had found different corrosion rates for steels containing different amounts of certain minor constituents, whereas the authors had not, therefore the authors' experimental methods were useless owing to low rates of oxygen supply. The argument was based on the fallacy that one type of experiment was sufficient to elucidate the "mechanism of corrosion" generally, and to predict results in other types. A qualitative knowledge of the mechanism did not enable predictions to be made about corrosion velocities in widely differing conditions, because of the alteration in the relative importance of some of the factors involved, and particularly the alteration of the physical characteristics of the corrosion products. To quote results obtained in experiments using half-immersed specimens (*see* reply to Dr. Bannister), intermittent spraying, drops as a corrosion medium, specimens shaken in tubes containing small volumes of aerated liquids, or specimens exposed to the atmosphere, as diminishing the value of the results obtained in conditions of total immersion in nearly stagnant or only slowly-moving liquids, was to display ignorance of the profound effect which the experimental conditions might have on the results. The phenomena observable when, for instance, corrosion occurred in $N/2$ NaCl in conditions like shallow immersion, drop tests, &c., where the oxygen supply was such that a high concentration was continuously maintained at the metal surface, were widely different from those at greater depths where the concentration was not maintained at a similar high value. Both sets of results were significant, and could be welded into a single coherent system of corrosion knowledge. But deductions from one type of conditions to the other could not be made, and experimental results were applicable in practice only to the like conditions. The nature of the oxygen supply and the nature of the corrosion products characteristic of the different conditions used were not the only factors which differentiated the authors' results from those of Dr. Evans and his Cambridge associates; another was the period of the experiments; in the drop tests and those with partial immersion, only the initial corrosion rates were studied

at Cambridge, and the nature of the metal surface might exercise an effect relatively great when experiments were only continued for a few hours.

Dr. Evans referred to the *atmospheric* tests of the American Society for Testing Materials in order to show that the authors' results were exceptional, but he omitted to mention that the *complete immersion* tests of that Society (with which alone the authors' results were comparable) agreed with the results in the present paper (*see* p. 167). Friend's[1] field tests in sea water also showed similar results to the authors'.

As regards the fourth paragraph of Dr. Evans' communication, it was quite wrong to say "the imperfections of the thermostat had saved the situation." The authors simply adopted a technique which reduced convection currents to an easily reproducible minimum, so as to provide a basis for further work on the effect of liquid movement. The authors claimed that the control was standardised and reproducible, since it had been possible to repeat results after intervals of up to seven years, although the experiments had been carried out at different times by seven different individuals. This point was further discussed in the reply to Dr. Mears.

The calculation by Dr. Mears, to which Dr. Evans referred, used the figure given for rust sludge *settled during* 530 *days*, which gave a higher density than would correspond to the newly-formed corrosion product, the density of which was not known, but which, for reasons stated in the paper, must be low. Also, the amount of convection could not be estimated, because it depended not only on the difference in density between the falling material and the water but on the *amount* of material available. The total production of rust, some of which adhered to the metal, in the standard experiments in $N/10$ KCl was about 14 mg. per day. It was probable that a much greater quantity of water fell by convection during one day. Dr. Barr calculated that 3 mg. of water might fall at each alternation of temperature of $0{\cdot}05°$ C. Usually the period of one alternation was about 20 sec., so that on this basis about $4{\cdot}32$ grm. of water would fall in one day, as against less than 14 mg. of corrosion product; usually, however, the temperature variation was much less than $0{\cdot}05°$ C.

However, the matter was more easily tested by experiment than by calculation; it had been found that if the corrosion vessel, containing corrosion products accumulated in $N/10$ KCl for 77 days, was vigorously shaken so that little product remained on the metal, the oxygen absorption reading for that day was only increased from $0{\cdot}85$ ml. to $1{\cdot}10$ ml., and for subsequent days was $0{\cdot}85$ ml. Thus, the settling of the large accumulations

[1] Eighth and Thirteenth Interim Reports of the Institution of Civil Engineers' Committee on Deterioration of Structures in Sea Water. Published by H.M. Stationery Office.

plus the effect of shaking only increased the reading by less than 30 per cent.; evidently the settling of a single day's corrosion product contributed only a trifling amount to the total amount of oxygen absorbed.

The authors certainly considered that half-immersed specimens were rationed with oxygen, since the corrosion rate under oxygen was about five times that under air. Dr. Evans' theory about "cathodically active points" was interesting, but the authors could not confirm one of the experiments on which it was based, for their own experiments with partially-immersed specimens showed no appreciable difference in corrosion rate between mild steel and highly-purified iron, though the experiments were conducted for much longer times than those of Dr. Evans. This was indicated in Table XXXI., p. 144.

Dr. Evans did not seem to grasp the advantages of the oxygen absorption method of measuring corrosion. These were: (1) A corrosion/time curve could be obtained from a single specimen, thus saving the preparation and the possible errors involved in the use of a large number. (2) For a similar number of points on the curve the time occupied was much less with the oxygen absorption method; this was important when twenty-four experiments, the authors' normal complement, were being conducted simultaneously. (3) The corrosion due to hydrogen evolution was separately determined, a matter that was sometimes highly important. (4) The time taken in setting up and taking down an experiment was large in comparison with the time taken for a reading.

Only a relatively few analyses of corrosion products were necessary to ascertain the proportion of oxygen used in the oxidation of the ferrous iron, and these alone would not define a corrosion curve accurately.

As regards the inaccuracy of the oxygen absorption method for measuring the corrosion during the first day or two, this had been recognised by the authors from the start, and no use had been made of oxyen absorption measurements in the first two days, since they did not correspond with the corrosion. During this period the authors used loss of weight tests, but they were mainly concerned with rates in long-time tests. The method was limited in its application, like any other, but had been found very satisfactory for the conditions being investigated. It should be noted that good agreement could be relied upon between the corrosion calculated from the gas measurements and analyses of the corrosion product and the corrosion measured by loss of weight.[1] Dr. Mears[2] had called the authors' attention to a

[1] G. D. Bengough, A. R. Lee and F. Wormwell, *Proceedings of the Royal Society*, 1931, A. vol. 134, p. 314.

[2] Private communication.

mistake in one of their papers,[1] where the corrosion in the early stages was expressed as "oxygen absorbed (c.c.)." This should have been "corrosion expressed as c.c. of oxygen," since the corrosion was measured as the loss of weight of the specimens, and from this was calculated a figure for the oxygen used by the specimen, partly from the oxygen initially in the solution and partly by absorption from the gas. In Fig. 21 (inset) (p. 137) of the present paper the curve was given correctly as "loss of weight, mg."

Dr. Evans stated that "the established fact that, at a non-corroding area of metal, the settling of rust from a corroding area greatly increased the chance of corrosion, was commonly attributed to 'oxygen screening' by the settled rust, which would tend to make the screened area anodic." Now, the authors had found in many cases that areas had been covered by a layer of ferric oxide up to 2 mm. thick for periods of 200 days without becoming corroded. Also, they maintained that, since in many cases large accumulations of rust which completely covered their specimens failed to cut down the corrosion rate, there was no *direct* evidence in those cases that oxygen screening had any appreciable effect.[2] In certain cases the authors had found evidence of a different action of the products (see later).

In order to prove that oxygen screening did occur in the authors' experiments Dr. Evans used the dangerous method of analogy by quoting Vernon's work on atmospheric corrosion, ignoring the fact that Vernon had himself emphasised the difference in mechanism between the corrosion in his experiments and that in immersed conditions. The fact that parabolic corrosion/time curves had been obtained in both cases did not mean that the explanation was the same. In atmospheric conditions the parabola persisted for long periods of time, but in immersed conditions it persisted for about two days only, after which the curve became linear, with a single sharply-defined break to a lower slope, for periods of up to 200 days, notwithstanding the piling up of corrosion products; after this the slope of the curve increased. The explanation of the two-day parabola was probably that an obstructive anodic film was formed, for during this initial period the corrosion products were almost confined to the corroding areas and hardly encroached on the uncorroded areas.

Dr. Evans' remarks on his own work with Dr. Mears on the passage of oxygen through different corrosion products gave the

[1] G. D. Bengough and F. Wormwell, *Proceedings of the Royal Society*, 1933, A. vol. 140, p. 418.

[2] G. D. Bengough, A. R. Lee and F. Wormwell, *Proceedings of the Royal Society*, 1931, A. vol. 134, p. 337. G. D. Bengough and F. Wormwell, *ibid.*, 1933, A. vol. 140, p. 412.

authors their first opportunity of expressing their views on it. They objected to it on the quite general grounds on which they objected to some other work of Dr. Evans and his associates, namely, that it had a quite unknown relation to actual corrosion experiments, and any interpretation of it must be based on an assumed analogy ; in fact, this particular piece of work was an attempt to correct results obtained from direct corrosion experiments by experiments in which the highly-important corrosion products were not only not being continuously produced but had been treated in quite abnormal ways, for instance by centrifuging. The results of direct corrosion experiments always afforded a safer basis for knowledge than any indirect work, which, at best, could only afford supplementary information, and at worst might be quite misleading. By actual corrosion experiments, the authors had themselves shown clearly that corrosion products could either cut down corrosion rates, or act as quite neutral substances even when present in such large quantities as to cover completely the whole metal surface ; the precise behaviour depended on the exact physical condition of the products, and this could only be obtained with certainty in an actual corrosion experiment.

The last paragraph and preceding sentence of Dr. Evans' communication the authors regarded as totally unjustifiable. The Evans-Mears work on the screening power of rust was done to support Dr. Evans' criticism of the authors' papers, in which the latter maintained, as a result of much accurate experimental work, that masses of corrosion products often failed to act as oxygen screens. Had the authors been consulted before the Evans-Mears work was begun they would have expressed the opinion on quite general grounds that it would be useless for the purpose of throwing light on corrosion experiments. The responsibility for the admitted waste of time rested solely on the shoulders of Dr. Evans, who would find that " the really promising lines of work " consisted of actual corrosion experiments continued for reasonable periods of time.

When Dr. Evans stated that the authors' views " had turned out, on investigation, to be based on a very slender foundation," he overlooked the fact that they were based on a body of strictly comparable and reproducible quantitative *corrosion* data obtained from experiments continued for long periods of time, continuously collected for seven years, and supplemented by microscopic and other observations on the distribution of corrosion at various stages of experiments and on the nature of the corrosion products. Such a body of strictly comparable data had never before been collected, and it was on such data that the proper understanding of the mechanism of corrosion would, in the authors' opinion, ultimately be based.

In reply to Dr. Hoar, the authors thought that electrochemical measurements undoubtedly could give valuable information in certain cases, but they did not consider they had such general application as direct determinations of the corrosion velocity. Moreover, in some cases electrochemical measurements alone could be misleading.

As regards the fourth paragraph of Dr. Hoar's remarks, it seemed that the view there expressed was quite different from that of Dr. Evans, though Dr. Hoar in his opening sentence stated that he associated himself with Dr. Evans' view. Dr. Evans insisted that all the authors' experiments were under strict cathodic control owing to "oxygen starvation," and that the reason why different corrosion rates were obtained for zinc and iron was because of the different specific gravities of the corrosion products, but Dr. Hoar now stated that the nature of the metal and of the electrolyte were alone sufficient to account for the differences, thus abandoning the "oxygen starvation" view.

Dr. Hoar's criticisms about the assumption of anodic films were very interesting. The authors could assure him that they had carefully considered the alternative explanation of control by cathodic films, but had concluded that it did not fit the facts as well as the postulate of restrictive anodic films. The authors could not agree to Dr. Hoar's suggestion that the results could be explained by the nature of the metal and of the electrolyte, without reference to an anodic film, and would refer him to the fact that in 4·4-cm. vessels under oxygen the rate of corrosion of steel completely immersed was much greater in $N/10$ KCl than in $N/10{,}000$ KCl for the first few hours, after which the rate in $N/10$ KCl fell so rapidly that it was less than that in $N/10{,}000$ KCl after two days and remained less for over 100 days. On Dr. Hoar's view this could only be explained if the anode potential, as controlled by the electrolyte alone, were more basic in the $N/10{,}000$ than in the $N/10$ KCl, which appeared highly improbable.

The authors' experiments in NH_4Cl and sodium citrate appeared to point to the importance of a film, and the results in $N/2$ NH_4Cl under argon suggested an anodic film. Also, on the hypothesis that a cathodic film restricted the rate at which steel could use the available oxygen supply in NaCl and KCl solutions, it was difficult to explain the many cases in the authors' work in which the corrosion rate had remained constant at its depressed value while the protected areas had gradually diminished and finally disappeared. On Dr. Hoar's view this enormous change in the nature of the cathode surface, from a film-covered turned metal to a corroded roughened one, should affect the corrosion rate. The authors would also refer to the argument given in the second paragraph of p. 137 of the paper.

The authors agreed with most of Dr. Hoar's remarks on the effect of NH_4Cl in preventing the formation of protective films by the buffering action.

With regard to the third paragraph of Dr. Hoar's communication, it was true that the authors had made no electrochemical measurements to support their views. They had to choose between such measurements and direct velocity determinations, and naturally chose the latter as the more fundamentally sound. They had tried to express and explain their results in electrochemical terms; on previous occasions when they had not done so they had received strong protests from the Cambridge school.

Dr. Mears had omitted to read certain parts of the paper if he thought that the authors were proposing the use of their standard oxygen-absorption test as a kind of universal test simulating "practical" conditions; a specific statement to the contrary was made on p. 128, third paragraph (see also reply to Dr. Bannister, first paragraph). The question of a comparison of the authors' results with those in service conditions had been dealt with in the first paragraph of the reply to Dr. Evans.

The points raised in the fourth paragraph of Dr. Mears' communication had been dealt with in replying to the similar comments by Dr. Evans. There was no reason why another investigator should not reproduce the authors' results by using the same technique. If he used a different accuracy of temperature control or failed to minimise vibration (as often happened) he would obtain corrosion/time curves of a similar form but with different slopes. If this happened his results would still be comparable with the authors'. It would only be necessary for him to determine the slope of the (*b*) portion of a corrosion/time curve of, say, mild steel in $N/2$ NaCl under oxygen in a standard vessel. From the large body of data accumulated at Teddington it could then be stated definitely that his rate of oxygen supply was a definite multiple of the rate in the authors' apparatus, and all his data would be comparable with those of the authors. The authors did not share the Cambridge school's horror of "oxygen starvation," which occurred under many ordinary industrial conditions of total immersion and even partial immersion (see reply to Dr. Evans).

It was satisfactory to find that seven of the nine conclusions on partially-immersed metals in a previous paper were accepted by the Cambridge school, who appeared to have gradually edged towards them from their earlier positions. The reason why the subject of oxygen screening was "avoided" in these conclusions was that this was dealt with at length in another portion of the same paper, the final conclusions of which did not appear to have been accepted by either Dr. Evans or Dr. Mears, and were generally agreed to constitute a different view of corrosion from that of Dr. Evans.

COMMUNICATION.[1]

By W. H. DEARDEN, M.Sc., A.I.C. (Bristol).

A Note on Reproducible Sulphur Prints.

The object of this note is to draw attention to three methods of reproducing Baumann sulphur prints relatively quickly and economically, without the use of a camera. The principle of the first method is not new, having been already described elsewhere,[2] but the second and third methods are modifications which have been found to work quite successfully. All three depend on the use of photographic papers having properties which are, perhaps, not very well known.

It is a common experience that it is seldom possible to obtain more than one or two satisfactory Baumann prints from a steel surface without having recourse to considerable regrinding. The usual plan adopted when several copies of a given print are required is to photograph the latter at full or reduced size and then employ the negative in the ordinary way. The methods described below not only render cameras and plates unnecessary, but also enable reproductions to be made at full size, whatever that may be.

In the first method use is made of "photo-mechanical bromide paper." This material is very thin, and after development and fixing is sufficiently translucent to enable contact prints to be made through it. The translucency is much improved by applying to the paper backing a small quantity of a clear mineral oil such as that supplied for typewriters. The procedure, therefore, for making and reproducing sulphur prints with this material is as follows.

A piece of the paper is soaked in 5 per cent. sulphuric acid and applied to the steel surface for a few minutes, taking rather special care to avoid the formation of bubbles between steel and paper. After washing, fixing, and drying this positive print, a small amount of oil is rubbed over its paper back, and it is then used to make a negative print on a second piece of the same paper. This second stage is, of course, carried out in a dark room. The dried negative print obtained in this way is oiled in its turn and is then ready for the production of any required number of positive prints on ordinary bromide paper. These reproductions, although similar to the original sulphur print, are

[1] Received October 19, 1934.

[2] H. Baars, A. Prill and M. Werner, *Stahl und Eisen*, 1932, vol. 52, p. 1291

in black and white, but they can, if necessary, be toned to resemble the brown shades of the latter.

In the second method advantage is taken of the properties of the photographic material known as " stripping paper " or " strip film." This consists of a strong paper base coated with a comparatively thick gelatine emulsion layer, which is so attached to the paper that, after developing, fixing and drying, it can easily be stripped from the paper base and may then be employed exactly as any ordinary positive or negative film.

With this paper the first, or positive, sulphur print is obtained in the usual way. Contact between steel and paper should be maintained long enough to obtain a fairly dark print. This is easily accomplished, because the thick gelatine film retains more acid than the thinner one on the normal type of bromide paper. Then, after fixing and washing, the wet print is immersed for a minute or two in a 5 per cent. solution of glycerine in water, and, without further washing, set aside to dry. The object of the immersion in glycerine is to make the gelatine soft and pliable, so that it can easily be made to lie flat after stripping. The latter process is carried out quite readily after drying by carefully inserting a blunt knife or razor blade at a corner of the print and firmly peeling the film from the paper base in one continuous movement. As there is a tendency for the film to frill at the edges of the paper during the making of the print, the latter should be trimmed before stripping.

The positive film obtained in the above way is now used to make a negative contact print on another piece of stripping paper. The making of this negative is carried out in a dark room, and if the gelatine film has an anti-halo backing care must be taken to remove the latter in a suitable bath. The print, after final washing, is treated with glycerine as described above and then set aside to dry. On subsequent stripping it provides the " negative " film which forms the source of the reproductions required.

Of the two methods so far described the second may be found to give the clearer and more sharply-defined reproductions, but some care is needed to avoid disappointing results. The stripping paper must not soak too long in the sulphuric acid, otherwise trouble will be experienced owing to its tendency to slip about on the surface of the steel. The extra thickness of the gelatine increases this tendency considerably. It is advisable also to use a chrome-alum fixing bath to prevent blistering of the film during washing, as this phenomenon may otherwise be found to occur with considerable frequency. The main difficulty, however, is a mechanical one, and arises from the liability of any sharp edges on the steel surface to cut or damage the gelatine film under the pressure employed to make contact, particularly if a squeegee is

being used. To prevent this it is advisable to round off the edges slightly and, of course, to avoid excessive pressure.

The third method is an obvious combination of the first two, and consists in making the preliminary sulphur print on "photo-mechanical" paper, then from this obtaining a negative contact print on "stripping" paper, and finally using the film from the latter for the production of positive copies. By proceeding in this way any difficulty associated with the use of stripping paper for making the original sulphur print is avoided, but otherwise all its advantages are retained.

COMMUNICATION.*

By E. JIMENO and I. GRIFOLL (University of Barcelona, Spain).

Electro-Chemical Interpretation of "Cleaning."

For a long time the authors have been convinced that the cleaning of metals is of capital importance for the life of subsequent protective metallic coverings on them. In 1932 they made a research, of a more technical than scientific nature, on "cleaning."[1] At the time they considered only the two most important methods: The acid method, which is the usual one, and the electro-chemical, of more recent industrial application. They were able to determine the necessary quantitative consumption of acid which takes place during this rather complex cleaning action. They arrived at useful conclusions, which permitted them to control and determine the minimum consumption of acid. This knowledge concluded the technical aspect of the problem, and, therefore, at the time they did not pursue the scientific study of it.

Some hypotheses which the authors then put forward to explain the mechanism of this problem coincide with the solution given that same year by Evans and Hoar, who introduced local cells. They propose to explain this matter because of its importance in "cleaning."

A very interesting work by Winterbottom and Reed,[2] a recent communication of Evans[3] and the information contained in a patent by Dunn[4] have decided them to present this note, which is to show the scientific aspect of "cleaning," and to give further coherence to the whole problem concerning the acid and the electro-chemical methods.

The composition of the oxide scales which cover the iron depends on the heat treatment it has undergone. Three oxides may be formed and in the following order: FeO, Fe_2O_3, Fe_3O_4, from the interior to the exterior, the first being almost always present in the largest proportion. At times the FeO may be completely absent. The way in which the acid reacts is very different according to whether the FeO is present or not. In the first case, the FeO goes into solution, since it is easily soluble in dilute acids; the other oxides fall to the bottom of the vat because of lack of binding material. The fundamental chemical reaction taking place is the following:

$$FeO + 2H^+ \rightarrow Fe^{++} + H_2O$$

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well established in practice, as the proportion of FeO dissolved at the beginning of the " cleaning " is nearly equal to the ferrous part which exists in the bath.

In the second case, that is, when the Fe_2O_3 or the Fe_3O_4 are in contact with the metal, the higher oxides of iron must be reduced electro-chemically to FeO, which is then attacked by the acid. Hoar and Evans envisaged a local cell at the contact of the metal with the higher oxide. This had to be the explanation of the more rapid solution of the oxide in contact with iron than when alone, and also of the fact that insoluble higher oxides of iron went into solution. This had been observed by several investigators. In the cells so formed :

$$Fe_2O_3 \mid \text{acid} \mid \text{metal}; \quad Fe_3O_4 \mid \text{acid} \mid \text{metal}.$$

it is logical to consider the iron as the anode, and the oxide as the cathode. Iron dissolves at the anode to Fe^{++}, and at the cathode a higher oxide is reduced to ferrous oxide.

The reaction at the anode is the electro-chemical solution of iron, giving ferrous ions. At the cathode two reactions may take place, theoretically : The electro-chemical reduction of the Fe^{+++} to Fe^{++} ions, or the deposition of H^+ ions, the ferric oxide being thus reduced to ferrous oxide by this atomic hydrogen. Thus the oxide is rendered soluble in the acid. Both ways thus lead to the same result, namely, the increase of ferrous-ion concentration. In the first instance the ferric oxide is dissolved, and on hydration it gives ferric ions which are electro-chemically reduced to ferrous ; on the other hand, by the second, the nascent hydrogen, produced electro-chemically on the ferric oxide, reduces it to ferrous oxide by a purely chemical reaction. The ferrous oxide, as is well known, is dissolved in weak acids, giving ferrous ions. The authors do not believe that the first action takes place, since the ferric oxide is very insoluble, and therefore the Fe^{+++} ion concentration is evidently below 10^{-7} (analysis does not prove its presence), so, as is known, no potential can be determined between the electrode and the electrolyte (Haber[5]).

This reaction discarded, the mechanism at the cathode must be :

$$2\ H^+ + 2\ \Theta \rightarrow 2\ H; \qquad 2\ H + Fe_2O_3 \rightarrow 2FeO + H_2O.$$

Therefore, the cell works by the solution of Fe to Fe^{++} at the anode, and the electro-chemical reduction of H^+ ions to atomic hydrogen at the cathode, this being continually depolarised by the reaction of the nascent hydrogen on the Fe_2O_3 or Fe_3O_4, according to the chemical reaction shown above.

These last ideas will be used to explain electro-chemical " cleaning," so giving unity to the interpretation of both operations.

Dunn put forward a process to be used on the large scale, which later was published by Mantell[6] and even applied in industry in the United States.

The electrolyte recommended is a mixture of sulphuric and hydrochloric acids with some sodium salt, preferably the chloride. The operation is carried out in the cold, but it is more efficient warm. The anodes are of lead; therefore the electrolyte always contains some lead ions because of the anodic action of the chloride ions. The iron piece to be cleaned acts as the cathode, with a current density of some 8–10 amp. per sq. dm. With lower densities, the operation goes much slower and is completely impracticable with densities as used in electroplating.

That author has found, contrary to the general belief and observation amongst electroplating experts, that when using such high current densities the clean iron is protected by a thin, well adhering film of lead without pores, which appears, nevertheless, under a spongy coat of the same metal, that is easily removed by brushing or even by a jet of water. By employing high current densities, Fe_3O_4, as well as incrusted sand, paint, &c., are eliminated from the cathode surface, and the lead can cover uniformly the clean piece. That author guarantees that only from 4 to 8 min. are required for perfect cleaning. In this method, according to the author, a very active evolution of nascent hydrogen is necessary at the cathode, and therefore the electrolyte (an acid bath) contains sulphuric, hydrochloric and even phosphoric acids, and also ions of sodium and of some other more noble metals such as lead or copper. The presence of these more noble ions favours the more rapid loosening of the scales, and the penetrating power of the bath becomes greater, thus ensuring the cleaning of holes and angles.

These properties of the bath, conferred by the presence of more noble ions, such as lead, are very evident, considering that the overvoltage of hydrogen is much higher for lead than for iron. As soon as a point or a small area of the cathode appears clean by reduction and subsequent solution of the oxides, lead deposits there and an overvoltage is set up. At this point, then, there is an increase of resistance, and therefore a lowering of the current density, which automatically becomes greater at other points. The reason for the deposition of the lead only on clean iron is now evident, since in these regions the cathode potential, which corresponds to the evolution of hydrogen against the hydrogen ions in the electrolyte, will be negative enough to permit the deposition of Pb^{++} ions. On the other hand, at the regions covered with oxide, the hydrogen is depolarised on being liberated on the ferric oxide, which it reduces, the cathode potential is more positive at these points (thus increasing the current density.

as already mentioned), and therefore the deposition of Pb^{++} ions is impossible.

The mechanism of cleaning by the acid and the electro-chemical methods have thus the same basis. In the first, cleaning by the acid method, the action takes place because of the formation of the before-mentioned local cell, maintained by the tendency of the iron to go into solution and by the depolarising action of the oxide on the hydrogen deposited on it. In the electro-chemical cleaning method, which is of a more intense nature, the electric current is supplied by a generator, and the hydrogen, so produced and liberated, is also depolarised by the higher oxides of iron; the latter are reduced to ferrous oxide, and this is soluble in the acid, as in the previous method.

REFERENCES.

(1) *Anales de la Sociedad Española de Física y Química*, 1932, vol. 30, p. 794.
(2) *Journal of the Iron and Steel Institute*, 1932, No. II, p. 159.
(3) Private communication, June, 1934.
(4) United States Patent Office, Sept. 16, 1930.
(5) *Zeitschrift für Elektrochemie*, 1904, vol. 10, p. 433.
(6) *Metal Cleaning and Finishing*, 1931, vol. 3, p. 785.

ANNUAL DINNER.

THE Annual Dinner of the Iron and Steel Institute was held on Thursday, May 2nd, 1935, at the Connaught Rooms, Great Queen Street, W.C.; Sir Harold Carpenter, Ph.D., D.Sc., F.R.S. (President of the Institute), occupied the Chair, and the company numbered over five hundred. Those present included The Rt. Hon. Walter Runciman, P.C., M.P., The Rt. Hon. Lord Rutherford of Nelson, O.M., F.R.S., The Rt. Rev. Lord Bishop of Gloucester, C.H., M.A., D.D., The Rt. Hon. Lord Stonehaven, P.C., G.C.M.G., Sir Richard Gregory, Bt., F.R.S., Mr. W. R. Lysaght, C.B.E., Mr. E. J. George, Sir Andrew Duncan, M.A., LL.B., Col. Sir Charles Wright, Bt., K.B.E., C.B., Col. J. B. Neilson, Sir John Field Beale, K.B.E., The Rt. Hon. The Viscount Falmouth, Professor J. D. Cormack, Dr. T. Swinden, Mr. Laurence Holland, Mr. H. Spence Thomas, Col. A. E. Davidson, D.S.O., Mr. Maurice E. Denny, C.B.E., Dr. W. H. Hatfield, F.R.S., Mr. Arthur Dorman, Col. E. E. B. Mackintosh, D.S.O., Sir Frederick Mills, Bt., M.P., Mr. O. Mueller, Capt. R. S. Hilton, Sir John Petavel, K.B.E., F.R.S., Mr. F. W. Harbord, C.B.E., Mr. C. P. Sandberg, C.B.E., Professor A. M. Portevin, Professor Henry Louis, D.Sc., Sir Charles Boys, F.R.S., Mr. B. Talbot, Sir William Larke, K.B.E., Mr. A. W. Laskey, Mr. J. Craig, C.B.E., Sir Richard Redmayne, K.C.B., Mr. Cyril Lloyd, Mr. H. A. Reincke, Mr. H. B. Jacks, Lt.-Col. W. Routledge, Mr. A. R. Smith, Major F. A. Freeth, Mr. A. Pugh, Mr. C. W. Hill, Mr. C. S. Andrews, Mr. A. Hutchinson, M.A., Mr. S. R. Lysaght, Mr. D. C. Lysaght, Mr. E. C. Lysaght, Mr. A. Granjon, Dr. H. J. Gough, F.R.S., Mr. H. F. Hodgson, Mr. J. H. Paterson, Mr. Loughnan Pendred, Dr.-Ing. A. Rapatz, Rear-Admiral A. G. Cronsay, R.N., Dr. A. McCance, Mr. G. N. M. Bland, C.M.G., Mr. W. J. Brooke, Capt. H. Leighton Davies, Sir R. Murray Hyslop, Kt., J.P., Dr.-Ing. A. Dörnen, Mr. J. E. Languepin, Dr.-Ing. F. Faltus, Dr.-Ing. K. L. Zeyen, Mr. J. E. James, Sir Peter Rylands, J.P., Mr. H. E. Cookson, Mr. I. F. L. Elliott, Dr.-Ing. B. Matuschka, Col. Sir William R. Campion, K.C.M.G., D.S.O., The Hon. T. G. Murray, Dr. A. B. Kinzel, Mr. E. F. Law, Engineer Vice-Admiral Sir Robert B. Dixon, K.C.B., Engineer Rear-Admiral W. Scott Hill, Mr. M. Tigerschiöld, Mr. R. Quijano, Dr. P. D. Merica, Mr. Luis Barreiro, and Col. The Hon. H. C. Guest.

The Toasts of "His Majesty the King," and "Her Majesty the Queen, His Royal Highness the Prince of Wales and the other Members of the Royal Family," were proposed by the President and loyally received.

The Rt. Hon. Lord Rutherford of Nelson, O.M., F.R.S., said that when he was asked by the President to propose the Toast of "The Iron and Steel Institute" he gladly accepted, because the President had been a valued colleague of his in his young days at Manchester. Moreover, he noticed that the first President of the Institute was the seventh Duke of Devonshire. Whether the iron entered into the Duke's soul or acted as a tonic he did not know, but a year or two later, in his capacity as Chancellor of the University of Cambridge, he presented a considerable sum for the building of the Cavendish Laboratory at Cambridge, over which personally he had the honour to preside.

Another reason for his feeling quite at home was that he knew the President very well indeed. He had first met Sir Harold at the National Physical Laboratory, and then when he was the first Professor of Metallurgy at the University of Manchester; and he (Lord Rutherford) pronounced the farewell oration over him when he left to go to the Royal School of Mines in Kensington.

The President's full name was Henry Cort Harold Carpenter. The name "Cort" had always appealed to him, and there was some notable history underlying it, for Henry Cort, of whom the President was the great-great-grandson, was one of the most notable figures more than a hundred years ago in the development of the iron industry. Henry Cort was the first to discover the method of puddling iron which was in use to this day, and was the first man to use grooved rolls in rolling iron. His business flourished owing to these new inventions, and some of his friends in the Admiralty offered him funds to invest in it. It transpired later, however, that apparently some of those funds had been derived from Government sources. The blame was promptly and naturally placed on Cort for perverting the moral nature of the simple-minded civilians in the Admiralty; his patent was sequestrated, and as a result he descended to poverty and died in 1800 in neglect.

The moral to be drawn from that pathetic story was, he thought, to tread delicately in the presence of the Board of Admiralty, and he might add of the Board of Trade.

Cort must have been a very great man; in 1856 *The Times* said of him that he was "the Tubal Cain of our century and of our country and the father of the British iron trade." As some evidence of the regard which American steelmakers had for the great pioneers of the iron and steel trade of this country, it might be recalled that in 1932 Mr. Charles Schwab declared that every great process in the manufacture of steel had come from Great Britain. That was a statement which members of the iron and steel industry in this country might think was deserved, but, after all, it referred to days gone by, and he wanted to speak of the present time and of the days to come.

We in this country were in a sense the pioneers of the iron and steel industry, and we ought to have made, and in fact did make, great discoveries in the early stages. Since that time, however, the iron and steel industry had assumed much greater proportions in some other countries than in our own, and it was proper and inevitable that some of the important discoveries which were used to-day had not had their origin in this country. One might mention, for example, the electric arc furnace of Héroult, the high-frequency furnace of Northrup, the high-speed steels of Taylor and White, and the carbide cutting tools which were developed in the German Osram laboratories. Those were important developments which had been found very useful in this country.

In the future we could not expect to be responsible for all the great discoveries in the steel industry, but he hoped we would provide at least our share, if not more. The older he became and, he hoped, the wiser he grew, the more was he convinced of the enormous importance of research to industry. He knew that the iron and steel industry was quite awake to that general problem, and that many of the great firms had excellent laboratories for the study of metallurgical problems connected with their industry. There was also an Iron and Steel Industrial Research Council which the Department of Scientific and Industrial Research, of which he had the honour to be Chairman of the Advisory Council, had tried to help as far as possible. A great deal to develop that research had been done by Sir William Larke, and he hoped the industry would see that it was generously supported and the development was continuously progressive.

The Institute controlled funds for the provision of Carnegie Scholarships, but it seemed to him that the sum was not so large as it ought to be. He hoped the Institute would see that general, fundamental research was continued and that a living wage was paid to the men who were asked to do it.

What of the future? There had been great changes in the industry during this Jubilee Year, but it would change at least as much in the next twenty-five years as it had in the past twenty-five, and there were great possibilities before the present generation. They had seen steel produced the tensile strength of which had been increased from 20 tons to 100 tons and more to the square inch; the physicist and the mathematician had been tackling the problems of the industry, and it was now known that the tensile strength of a piece of steel was not much more than 1 per cent. of what it ought to be in a properly designed and conducted world. The fault apparently lay with the presence of microscopic cracks in a crystal, and one could well imagine some genius coming along and showing how those cracks could be eliminated.

He appealed to the Institute to take a far-sighted view of the

problem of research, and to cast their bread upon the waters, and after many days it would return.

He had pleasure in proposing the toast of the Institute, coupled with the name of its distinguished President, Sir Harold Carpenter.

Sir HAROLD CARPENTER, Ph.D., D.Sc., F.R.S. (President of the Institute), who responded, expressed the pleasure felt by all members of the Institute in having Lord Rutherford present that evening. As Lord Rutherford had said, they were old friends; he had wanted to secure Lord Rutherford's presence not only on account of their personal friendship, but because Lord Rutherford was Chairman of the Advisory Council of the Department of Scientific and Industrial Research.

It was a remarkable fact that it had been left to one of the greatest physicists who ever lived to tell him more about his metallurgical ancestor, Henry Cort, than any metallurgist had ever done, and he was deeply touched that Lord Rutherford had gone so deeply into his history. Personally, he had been brought up on the phrase from *The Times* which Lord Rutherford had quoted: "The Tubal Cain of our century and of our country, the father of the British iron trade," and he remembered that the same article estimated that Cort's discovery had saved England more than the national debt, which then stood at £600,000,000.

There were a few facts with regard to the Institute which he would like to mention. One important step taken by the founders was from the very beginning to admit members without regard to their nationality; the Institute had had foreign members since the commencement. That showed true wisdom; the Institute was set up to assist the industry by scientific methods, and the steelmasters quite rightly said "Let us have the best information and knowledge, regardless of where it comes from." The result of that was that if every other metallurgical publication were destroyed the technical and scientific knowledge contained in the *Journal* of the Institute would enable the industry to carry on; practically everything was there.

Lord Rutherford had very rightly emphasised the value of purely scientific work in a technical institute. The task of the Institute, of course, was to maintain a true balance between the work which was of undoubted practical and immediate importance and the long-range work. He was glad that Lord Rutherford had drawn attention to the Carnegie scholarships, which, although they did not produce enough money to give a man anything like affluence, were of great assistance; a keen man could do a great deal with £100 a year.

It had occurred to him to test the value of those scholarships in the following way. The scholarships had been in existence for about thirty years, and it seemed to him that if they had been the

means of enabling a man to do valuable work one might expect to find some Carnegie scholars among the Bessemer Medallists of recent times. The Bessemer Gold Medal was the highest honour which the Institute could bestow, and was given to a man only at a comparatively mature period of life. He thought, therefore, that it was of interest to find that of the last nine Bessemer Medallists four were former Carnegie scholars.

He would like to say a word about a special feature of the present meeting of the Institute. About a year ago the Department over which Lord Rutherford presided asked the Institute to make itself responsible for the holding of a Symposium on the subject of welding. The fact had to be faced that welding as an art had invaded every form of construction, and nobody knew what scientific work was most required for the elucidation of the problems raised. He would like to refer to the valuable work that Dr. Gough had done in bringing the Symposium into existence. Invitations were sent out all over the world, and 150 papers were received, dealing with different aspects of welding. It was intended that when the discussions were ended, the Organising Committee should prepare a report in order to advise Lord Rutherford's Department of the directions in which it was thought that further research was required. That should be most valuable. At the first session more than nine hundred people were present, and he had been told by a member of the Council of The Institution of Civil Engineers that it was the largest meeting ever held in their building. The luncheon interval sometimes had fatal results on the subsequent attendance, but more than seven hundred people were present when the meeting was resumed in the afternoon. It was obvious that there was immense interest taken in the problem of welding to-day.

He would conclude by again thanking Lord Rutherford for the delightful way in which he had proposed the toast.

The Rt. Hon. Walter Runciman, P.C., M.P. (President of the Board of Trade), proposing the Toast of "The Iron and Steel Industries," said: It is a great honour to have the privilege of proposing the Toast of the Iron and Steel Industries, and it is especially fortunate that to-night the foundation for our speeches should have been laid by two such eminent pure scientists as Lord Rutherford and Sir Harold Carpenter. I have observed throughout life that if you wish to enjoy good writing you must go to the writings of the sailor, and obviously if you wish to enjoy good speaking you must go to the pure scientist. They have been talking of one aspect of this great industry, and now for a few moments we may think of another aspect of it. I fully appreciate the remarkable fact that after lunch you were able to muster seven hundred of yourselves in one room, but I do not

believe, if the President will allow me to say so, that they all came there in search of pure scientific facts ; I think they bore in mind what has already been said to-night, that man cannot live by bread alone, and they regarded bread as an integral part of a healthy man's diet.

What we are interested in, therefore, is not only the purely scientific problems which are the foundation upon which we build, but the prosperity of the industry itself. Without its prosperity there will be little or no research ; there will be no augmentation of scholarships ; there will be no extension of those practical experiments without which the industry cannot expand. If the industry itself is not prosperous, it will drag down with it into depression a dozen other industries almost as important as itself. It is because we have been deeply conscious of that fact that the Government and Parliament itself have devoted a great deal of attention in the last two years to providing conditions under which the industry can prosper.

Mr. President, you and Lord Rutherford have been exchanging the intimacies of your private lives for our delight ; will you allow me not to display or to expose the character of other people, but to make a confession myself. There was a time, not so far distant, when I regarded high import duties on any commodity, but especially on iron and steel, as being inimical to the prosperity of the country as a whole. But how the times have changed ! Our outlook is still the same ; we still hold the view that it is the prosperity of the country as a whole which must be our guiding principle ; but we are not blind to the fact that unless the iron and steel industry can continue to prosper it must inevitably decline, and that if it declines it carries with it far more than the fate of one group of great business men and tens of thousands of employees. If, therefore, I may make a confession, it is this, that when I surveyed British industry as I found it when I went back to the Board of Trade in 1931 I was more impressed by the fact that we could not hold our own in the world by the old means than I was devoted to principles to which I had given the best part of my political life.

I put up no defence for that, but I am sure you will allow me to say that unless we had approached problems in that spirit some of the fiscal events of the last two years, in which you have participated, would never have taken place. I remember telling one of my colleagues in the House of Commons, who criticised me severely when I piloted a tariff order through the House, that if he wanted the job well done he had better get a free trader to do it ; and there is a great deal of truth in that remark. A short time ago one of the most distinguished economists and statesmen in Europe—not of our own country—was talking to me about the possibility of the example which we had set in the

United Kingdom being copied in one or two comparatively free trade countries on the Continent, and he used this very simple phrase when I asked him what was likely to happen in his country ; he said, " When all the world has gone into the madhouse, I cannot afford to remain outside."

My very shrewd friend would have found many good reasons for dealing with the iron and steel industry as we have done if he had been in this country. What, putting it very simply, are the main objects of those who are responsible for directing and organising the commercial side of this industry ? You want to make profits—a perfectly legitimate aspiration. You want to make sure that your concerns not only can keep their heads above water, but are capable of unlimited expansion. With that object you must retain the largest portion of the home trade for yourselves and not allow it to slip into foreign hands. That is the beginning ; the second step is that you should be able to retain for your industry the custom abroad without which our foreign trade would be gravely diminished.

Now, by a tariff we can look after the home market, and I would lay down one or two very simple rules for that tariff. It must not be too big, for, if it becomes excessive, it may have reactionary effects amongst the consuming industries without which your prosperity cannot go on. Secondly, if it is too big it may lead to a reaction, and nothing would be more fatal for this or for any other great industry in this country than to have to exist under a condition of fluctuating policy. Let us make up our minds that having, under the pressure of events, embarked on our present policy, we shall adhere to it.

So much for the home market. But the foreign market is not so easily in our keeping, and it is at this stage that we approach the importance of the Cartel. The Cartel has stepped into a publicity during the past few months which it did not previously enjoy with the general public. A great many people now know that unless good terms are made with the Cartel our foreign markets must suffer. Unless good terms are made with the Cartel the markets of the foreign producers must also suffer ; they cannot have it all their own way, and nor can we. But we can make arrangements whereby the trade of the world, the consuming capacity of the world, can be adjusted to our requirements as well as to theirs. Those of us who were watching the procedure of the last few months observed, not without a certain amount of disquietude, that it was almost impossible to persuade our opposite numbers on the Continent that the British Government was serious in its intention not only to impose tariffs for the protection of the home market but to maintain them at an effectively high level, so high as to make the Continental members of the Cartel realise that it was better to be on good terms with us than to be

on bad terms with us. There are present here to-night some very distinguished representatives of the industry on the Continent, and I am sure they will not mind my expressing what I know to have been largely in the minds if not of themselves at any rate of their Governments. We wish them well; we want to be on the best of terms with them; but if we cannot have it one way we must have it the other.

I am very glad to say that, as you all know, the Cartel has now admitted into it its British members under a temporary agreement. I trust that that temporary agreement is going to be the beginning of an arrangement of a more permanent character. In these circumstances, the very high rate of duty for which we secured the consent of the House of Commons recently is not now so urgently needed, and we are prepared, under the advice of the Import Duties Advisory Committee, to ask Parliament to reduce the import duties; and we shall, I hope, be able to maintain them on a more moderate level so long as the Cartel are good enough to treat us well. It is just as well that that should be known from the mouthpiece of the British Government. I say it with no offence, but I say it without the least compunction, that we intend to stand behind the iron and steel industry.

It is in those circumstances that I express pleasure in being here to-night and wish the industry all prosperity. I can well understand the intense interest of your scientific papers—though I find the titles a little difficult to follow! I have little or no knowledge of your alloys; I do not know what "iron rich" means. But I do know that unless you can make ends meet we may as well all give up in despair; and it is because I hope that you will extend the margin of your prosperity, that your revenue will largely exceed your expenditure, that you will be able to see your works established on the most modern systems, under the guidance of the distinguished scientists who sit round these tables to-night, and that as a result of their advice and your prosperity and your abundant funds you will be able once more to resume and retain the lead in the world, that I have much pleasure in proposing this Toast.

Mr. E. J. GEORGE (Member of Council; Past President of the National Federation of Iron and Steel Manufacturers), who responded, said that his task in doing so had been made wonderfully easy for him by the courageous and statesmanlike utterance which Mr. Runciman had made in such a clear and helpful manner.

Mr. Runciman, in going to the Board of Trade, had undertaken one of the most arduous tasks of any member of the Government, but the hopes placed in him had been fully realised, and the industry and the country were grateful to him for all he had done.

Mr. Runciman had referred to the fact that in taking office he had been willing to deal with the realities of the situation without regard to his previous political outlook. One of the things which the Government did quickly, although after careful thought, was to provide a system of tariffs. One of the conditions which was then made by Mr. Runciman on behalf of the Government was a condition which the industry did not at all resent, but rather welcomed, namely, that they should not use the assistance which the tariff gave them to the detriment of the consumers, and so ultimately to their own detriment, and that they should not use it for the purpose of having an easy time, but in such a way as to create the utmost possible measure of employment while serving the interests of consumers and thus of the nation. The policy embarked upon and the conditions imposed undoubtedly assisted the industry in a most wonderful manner to rehabilitate itself.

If he might digress for a moment, he would like to pay a tribute to Mr. Runciman's signal success in the negotiation of trade agreements with other countries. Those agreements affected more than one trade, and he referred to them because of the close interrelation between the iron and steel industry and the coal trade. So judiciously had those agreements been negotiated that in practically every instance the stipulated percentages of British coal had been taken by the countries concerned. That had been of great benefit to that most depressed of all trades, the coal trade, on the prosperity of which the nation, and to a large extent the iron and steel industry, was dependent.

The Import Duties Advisory Committee, which Mr. Runciman had set up under the chairmanship of Sir George May, had done a great deal to assist the various industries of the country and had done much to restore their prosperity. They had won the confidence of both consumers and producers.

He would like to say to Mr. Runciman and to the public at large that the stipulation laid down when the tariff was imposed as to the efficiency of the industry had been honoured. The task was a great one, and had not yet been completed, but the movement was in the right direction. The National Federation of Iron and Steel Manufacturers, which Sir William Larke had guided through a dark period with great courage, skill and optimism, had been turned into The British Iron and Steel Federation with very much wider powers, and that had been done successfully, although the men associated with the industry were to a large extent men of strong character and individualistic tendencies. They were fortunate in having, to help them to complete their organisation, a man of outstanding ability and great tact, Sir Andrew Duncan.

The measures taken had fortunately had a great effect in relieving unemployment, which had decreased from 45 per cent.

to 25 per cent. in the last two years ; nor did that represent the full effect of the improvement, because employment had been more regular and there had been less short time. Much had been done to make the industry more efficient ; even during the dark years of depression many businesses spent large sums of money for this purpose, and his own company, in the five years preceding 1930, spent something like £5,000,000 in the hope that the employment which had been given for half a century or more in their area might be continued. Since 1931 the industry had spent about £20,000,000 of new money on improving itself, and was pledged to spend in the near future a further sum of nearly £10,000,000.

Mr. Runciman had referred to the Cartel. Now that their opposite numbers on the Continent realised the conditions under which an arrangement could be made, the industry in this country believed that they could bring the negotiations which were proceeding to a successful issue.

In conclusion, he would like, on behalf of the industry, to assure Mr. Runciman that they were highly appreciative of the efforts which the National Government and Mr. Runciman in particular had made to engender their greater prosperity ; and, realising the vital national importance of the highest efficiency in what was one of the country's greatest basic industries, their efforts to that end would be continued with all the ability and energy at their command.

Mr. W. R. LYSAGHT, C.B.E. (Past-President), proposed the Toast of "The Visitors," to which Sir RICHARD GREGORY, Bart., F.R.S., responded.

The proceedings closed with the Toast of "The President," which was proposed by Sir JOHN FIELD BEALE, K.B.E., and received with musical honours.

SECTION II.

NOTES ON THE PROGRESS OF THE HOME AND FOREIGN IRON AND STEEL INDUSTRIES.

CONTENTS.

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The Editor has been assisted in the preparation of these Notes by R. Elsdon, Librarian of the Institute.

MINERAL RESOURCES.

BRITISH EMPIRE.

The Lower Coal Series of North-West Gower. S. H. Jones. (Proceedings of the South Wales Institute of Engineers, 1935, vol. 50, No. 5, pp. 317–338).

EUROPE.

The Recent Developments in Siegerland-Wieder Iron Ore Mining. R. Schneider. (Stahl und Eisen, 1935, vol. 55, Apr. 25, pp. 457–460). After a brief indication of the type and importance of the iron ore deposits in the Siegerland and the Wiedbachtal, the development of output and an estimate of the reserves are discussed.

The Output Capabilities of the Lahn District. W. Witte. (Stahl und Eisen, 1935, vol. 55, Apr. 4, pp. 377–380). The author first discusses the economic relations in the Lahn District of Germany, and then goes into details regarding the deposits, stocks and supply of iron and manganese ores. He also deals with the importance of the occurrence of other minerals, such as phosphorite, bauxite and brown coal.

The Formation of the Amberg Iron Ore Deposits [Bavaria]. F. Trusheim. (Zeitschrift für praktische Geologie, 1935, vol. 43, Mar., pp. 45–48).

Mineral Industry of Yugoslavia. H. K. Scott. (Société des Ingénieurs Civils de France, 1934, Nov. 28: Iron and Coal Trades Review, 1934, vol. 129, Dec. 14, p. 937). The author describes the geological features of Yugoslavia, and points out that the minerals are State owned, and worked under licence. There are good deposits of lignite and brown coal, and iron ore is also mined. Two blast-furnaces and four steelworks comprise the steel plant of Yugoslavia. The author mentions the deposits of chromium, copper, aluminium and other ores.

AMERICA.

Mineral Industry of Alaska in 1933. P. S. Smith. (United States Geological Survey, 1934, Bulletin No. 864–A).

Core Drilling for Coal in the Moose Creek Area, Alaska. G. A. Waring. (United States Geological Survey, 1934, Bulletin No. 857–E).

The Book Cliffs Coal Field in Garfield and Mesa Counties, Colorado. C. E. Erdmann. (United States Geological Survey, 1934, Bulletin No. 851). There are four producing areas in this field—the Carbonera district, near the western boundary of the State, and the Grand Junction, Palisade and Cameo districts. The coals are of bituminous rank and occur in four zones, three in the Mount Garfield formation of the Mesaverde group and one in the Mancos shale, all of Upper Cretaceous age. The total reserves are estimated at about 5,103,000,000 tons.

Geology and Fuel Resources of the Southern Part of the San Juan Basin, New Mexico. Part I.—The Coal Field from Gallup Eastward toward Mount Taytor. J. D. Sears. (United States Geological Survey, 1934, Bulletin No. 860–A.).

Development, Equipment and Operation of the Blueberry Mine, Marquette Iron District. R. S. Archibald and L. S. Chabot, jun. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 601). This property is producing ore for the Ford Motor Co. The rock formation is chert, and the iron deposit is classified as soft-ore jasper or hard-ore jasper. The surface plant exhibits the best features of local practice together with many ideas derived from Ford factory practice. The plant is housed in one building, and the equipment is all electric, except for the heating unit; the mine is served by an electric sub-station adjacent to it. The ore produced is of a non-Bessemer grade which smelts readily on account of the high ignition loss; it has the following approximate analysis: Fe 50·00; P 0·086; Mn 0·60; Si 7·50; Al_2O_3 2·86; CaO 1·21; Mg 1·17; S 0·01; moisture 10·00; loss on ignition 5·64 per cent. The plant is economical in operation.

The Magnetite Deposit near Humacao, Puerto Rico. R. J. Colony and H. A. Meyerhoff. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 587). Magnetite deposits are widely distributed in Puerto Rico; the orebodies are mainly of contact-replacement origin and are associated with intrusive deposits of andesite and diorite. However, in the Humacao district there is an orebody of the magmatic type which is of some petrographic and possibly economic interest. The iron crops out on a ridge near the town of Humacao; the magnetite is associated with gabbroic quartz diorite. The contact ores on the island have an Fe_2O_3 content of about 73 per cent.; the Humacao samples yield 78·83 per cent. of Fe_2O_3 and 5·35 per cent. of TiO_2. Three exploratory tunnels have been driven into the ridge, and magnetite has been found within 30 ft. of the surface. Petrographic specimens show that at

the base of the ridge the rock is gabbroic anorthosite, in which grains of magnetite appear in plagioclase surrounded by hornblende. This magnetite contains ilmenite. As the ridge is ascended the magnetite increases in amount, and the feldspar decreases ; the rock is mainly pyroxene and hornblende containing magnetite inclusions which give rise to a schiller effect. The ore itself consists of granular magnetite surrounded by hornblende and pyroxene. Ilmenite is present in large plates or grains (this accounts for the relatively high content of TiO_2). Inclusions of spinel are also present. Geographically, and topographically, the deposit is favourably situated for exploitation ; the overburden is probably thin enough to permit open-cut mining. Much of the ilmenite could be magnetically separated, and the rest diluted by admixture with the non-titaniferous contact ores.

ASIA.

Geology of the Yuhsien–Mihsien Coal Field. C. C. Sun. (Geological Survey of China, Geological Bulletin No. 24, Sept., 1934, pp. 1–14).

A Chemical Study of Oil Shales in China. K. Ping. (Geological Survey of China, Geological Bulletin No. 24, Sept., 1934, pp. 15–31).

Geology of the Coal Fields of Sianghsiang District, Central Hunan. Y. S. Chi and P. Kao. (Geological Survey of China, Geological Bulletin No. 24, Sept., 1934, pp. 33–36). In central Hunan there are two types of coalfields ; the Lower Carboniferous coalfields, of no economic importance, and the Middle Permian coalfields of good coking coal.

Geology of the Changhsing Coalfields, Chekiang Province. Y. S. Chi. (Geological Survey of China, Geological Bulletin No. 24, Sept., 1934, pp. 37–45).

THE WORLD.

The Magnesite Deposits of Russia, Manchukuo, Japan, Sweden and Norway. L. Loch and K. A. Redlich. (Zeitschrift für praktische Geologie, 1935, vol. 43, Jan., pp. 1–10).

Chromium, its Ores, its Industry. M. Déribéré. (Métaux et Machines, 1934, vol. 18, pp. 309–312). The ores of chromium, their occurrence and treatment are described. Formerly, New Caledonia supplied the greatest proportion of chromite, but since 1924 Rhodesia has come to the fore as the principal source of supply of this ore.

The Ores and Applications of Zirconium. V. Charrin. (Génie Civil, 1934, vol. 105, Nov. 24, pp. 483–485). The author gives a short account of the ores of zirconium and of the deposits in Brazil, Senegal, Madagascar and France. The treatment of the ores and the applications of zirconium are touched on. The oxide, natural or obtained by treatment of zircon, is used principally in the manufacture of refractories, generally in admixture with magnesia, which increases the stability, and agglomerated by means of tar, phosphoric acid or boric acid. Its low electrical conductivity and high refractoriness make it useful for insulation in electric furnaces.

ORES—MINING AND TREATMENT.

The Valuation of Iron Ores. W. Luyken. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 55, No. 1, pp. 1–18: Stahl und Eisen, 1935, vol. 55, Apr. 11, pp. 419–421). The author presents a general discussion of the valuation of iron ores and of various factors that have to be taken into account.

The Carriage of Heavy Ore Cargoes. W. Halcrow. (Journal of the Royal Society of Arts, 1935, vol. 83, Apr. 5, pp. 461–470). The author discusses the transport of ore with special reference to ship construction.

Aerial Ropeway of Lincolnshire Iron Mine. (Iron and Coal Trades Review, 1935, vol. 130, Mar. 1, pp. 369–370). Illustrated particulars are given of the aerial ropeway in operation for transporting ironstone from the Nettleton Top Mine in Lincolnshire. The ropeway is on the monocable system, in which one endless steel wire rope supports and hauls the loads. The distance from the loading station to the return station is approximately 6,060 ft., with a difference in level of 205 ft. The plant is designed for a capacity of 75 tons per hr.

The Use of Mechanical Classifiers in Iron-Ore Dressing. G. G. Bring. (Jernkontorets Annaler, 1935, vol. 119, No. 1, pp. 1–28). Investigations on a laboratory scale show that Dorr classifiers can be used to treat heavy minerals, such as iron ores, if the overflow is kept sufficiently low.

New Sintering Plant at the Works of the Appleby-Frodingham Steel Company, Limited. (Iron and Coal Trades Review, 1934, vol. 129, Dec. 7, pp. 881–883). The layout and equipment of the Greenawalt sintering plant at the works of the above-mentioned company are described and illustrated. The plant is laid out for a maximum capacity of 800 tons of sinter per day of 24 hr. Both Lincolnshire and Northamptonshire ironstones are treated.

Third Study of the Magnetic Concentration of the Oolitic Iron Ores of the East [of France]. J. Seigle. (Revue de l'Industrie Minérale, 1934, No. 336, Dec. 15, pp. 585–591). The author first discusses the treatment (crushing and sizing, by wet or dry processes) of oolitic ores from Eastern France after they have been submitted to a magnetising roasting. He then gives consideration to the possibility of utilising the action of nitric acid for making comparative tests and for the actual process of

beneficiation, and the possibility of making calcium nitrate, which could be used as a fertiliser.

New Magnetic Separator for Concentration of Ores. C. W. Davis. (Steel, 1934, vol. 95, Dec. 24, pp. 37–38). Illustrated particulars are given of an alternating-current magnetic separator devised jointly by the author and R. S. Dean. The new separator uses alternating current of the ordinary frequencies (60 to 120 cycles) to produce a relatively low field strength (about one-half that of the coercive force of the mineral being treated), and effects rapid separation of the magnetised particles. The principle of operation is outlined and some representative results obtained on different iron ores are given.

REFRACTORY MATERIALS.

The Worksop Works of General Refractories, Ltd. (Iron and Coal Trades Review, 1935, vol. 130, Feb. 22, pp. 341–342). An account is given of the equipment of these works for the manufacture of refractory bricks.

Modern Refractories. W. F. Rochow. (Chemical and Metallurgical Engineering: Iron and Coal Trades Review, 1935, vol. 130, Mar. 15, pp. 449–450). The chemical and physical properties of modern refractory materials are outlined, and some of the more important grades are described.

Refractory Materials for the Iron and Steel Industries. A. B. Searle. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 158–160). The trend of modern practice is indicated and examples are furnished of present-day applications. Brief reference is made to the problem of insulation and insulating materials, whilst specifications and foundry sands are other matters touched upon.

Some Recent Advances in the Industry of Refractory Materials. G. Batta and L. Scheepers. (Revue Universelle des Mines, 1935, vol. 11, Jan. 1, pp. 10–20; Jan. 15, pp. 41–45). The authors present a review of recent advances in the knowledge, manufacture and use of refractory materials. They indicate briefly the various raw materials usually employed and the transformations which they undergo during firing, and summarise information regarding refractories of recent application, such as mullite, sintered corundum, siemensite, magnesium orthosilicate, refractory cements, &c. They mention recent innovations in the various phases of manufacture, and conclude with a reference to the various tests to which refractories are submitted.

The Examination of Some Special Refractory Materials. M. Lépingle. (Engineering, 1935, vol. 139, Mar. 8, pp. 245–248; Mar. 22, pp. 302–303; Apr. 5, pp. 353–355). Information is presented on the constitution and properties of a number of special refractory materials.

The Burning of Magnesite Bricks.—Part II. J. H. Chesters and C. W. Parmelee. (Transactions of the Ceramic Society, 1935, vol. 34, Mar., pp. 203–218). A test-piece mould designed to give pressure-compression curves up to 50,000 lb. per sq. in., and a modified reaction-expansion apparatus for work at 1,500° C. are described. By using a grading of the 70 : 10 : 20 type, high moulding pressure, and an addition of mucilage, unfired test-pieces of electrically fused magnesia having porosities as low as

15·5 per cent. were obtained. The pressure-compression curves of the materials examined all showed a fairly rapid falling off in the rate of compression with increasing pressure. Thus an increase in the moulding pressure from 4,000 to 12,000 lb. per sq. in. produced the same decrease in test-piece length as the change from 12,000 to 37,000 lb. per sq. in. The burning shrinkage on the test-pieces fell as the moulding pressure rose to 12,000 lb. per sq. in., and then remained essentially constant to 37,000 lb. per sq. in. After-shrinkage tests made on two low-iron and two high-iron commercial bricks showed that the initial rate of shrinkage was much greater for the high-iron bricks, being as high as 3·2 per cent. linear after two hours at 1,500° C. The shrinkage was found to be due to decreasing porosity, and not to increasing density of the magnesia.

The Burning of Magnesite Bricks.—Part III. J. H. Chesters, G. L. Clark, and K. C. Lyon. (Transactions of the Ceramic Society, 1935, vol. 34, Apr., pp. 243–249). Laue diffraction patterns were obtained from magnesite specimens in order to derive an estimate of the grain and crystal size, by comparing the spot sizes for mono- and poly-crystalline specimens (*see* Journ. I. and S.I., 1933, No. II. p. 482).

Young's Modulus of Elasticity at Several Temperatures for Some Refractories of Varying Silica Content. R. A. Heindl and W. L. Pendergast. (Journal of Research of the National Bureau of Standards, 1934, vol. 13, Dec., pp. 851–862). Young's modulus of elasticity was determined for ten brands of fireclay brick (48 to 52 per cent. of silica); two brands of silica brick (96 per cent. of silica); and one of high alumina brick (16 per cent. of silica). The determinations were made at room temperature and at 100°, 200°, 400°, 500°, 600° and 800° C., and in a few cases at 300°, 700° and 900° C. Six samples were tested through temperature regions of crystalline silica inversions at intervals of less than 100° C. The results show that the modulus of elasticity is affected greatly by the total silica content, modified by the form of the crystalline silica present and by the temperature. A general relation was found between the modulus of elasticity, the total silica and the linear thermal expansion.

Effect of Variations in the Alumina-Silica Ratio in Fused Refractory Materials upon Resistance to Metal Oxides. C. McMullen, A. A. Turner and G. J. Easter. (Journal of the American Ceramic Society, 1935, vol. 18, Jan., pp. 30–33). Pieces of electrically fused refractory, varying in composition from 63 per cent. alumina and 37 per cent. silica to 100 per cent. alumina, were heated in contact with cast iron and brass which were allowed to oxidise. The brick containing 80 per cent. alumina and 20 per cent. silica was least attacked in contact with cast iron.

The Permeability of Refractory Materials to Gases. Part IV.—The Influence of the Firing Process on the Permeability to Air of Fireclay Products. F. H. Clews and A. T. Green. (Transactions of the Ceramic Society, 1934, vol. 33, Nov., pp. 479–494). The permeability to air of three types of fireclay at stages representing the green to the finished state was measured and found to increase continuously up to 1,200°. It is concluded that as a result of firing over this range the number of pores decreases, but that their size increases. This is in keeping with the contraction which occurs on firing. Continued vitrification at temperatures up to 1,400° has been found to lead in five instances to an increase in permeability, and in five others to a decrease. It is suggested that vitrification *per se* leads to a decrease in permeability. The observed increases are attributed to the inability of certain types of material to withstand without cracking the strains imposed by vitrification and subsequent cooling. The low values found for the permeability of dried (120°) fireclay emphasise the strains which can be produced by undue haste in the water-smoking period. The low values for the permeability of the fireclay goods at 650° explain the extended time required for the complete elimination of carbon from some clays at this temperature.

An Apparatus for Measuring the Thermal Conductivity of Refractories at High Temperatures. J. L. Finck. (Journal of the American Ceramic Society, 1935, vol. 18, Jan., pp. 6–12). Apparatus for measuring the thermal conductivity of refractories at temperatures up to 2,000° F. is described, and the procedure and theory are discussed. Results for a light refractory insulating brick and silica and fireclay bricks are given.

Thermal Conductivity of Refractories under Operating Conditions. R. H. Heilman and R. S. Bradley. (Journal of the American Ceramic Society, 1935, vol. 18, Feb., pp. 43–48). Tests on silica, chrome, magnesite and proprietary bricks were carried out by inserting the materials as test panels in a small gas-fired box furnace. Conductivity curves and temperature gradients for the materials investigated are furnished.

The Reliability of Measurements of the Thermal Conductivity of Refractory Brick. J. B. Austin and R. H. H. Pierce, jun. (Journal of the American Ceramic Society, 1935, vol. 18, Feb., pp. 48–54). The apparatus employed gave results reproducible within 5 per cent. From their investigations the authors conclude that in the case of thermal conductivity measurements lack of reliability must be attributed to the method employed rather than to variation in the refractory.

Refractories for Coke Ovens. G. E. Foxwell. (Colliery Engineering, 1935, vol. 12, Jan., pp. 20–22). A discussion of the nature and properties of the refractory materials used in the construction of coke ovens.

The Evaluation of Coke-Oven Refractories. W. J. Rees. (The Coke-Oven Managers' Association, Feb. 8, 1935: Gas World, 1935, vol. 102, Mar. 2, Coking Section, pp. 6–8) The author discusses the relative merits of fireclay, semi-silica and silica bricks for coke-oven construction.

Limits of the Pressure and Thermal Stressing of Coke-Oven Walls. C. Koeppel. (Glückauf, 1935, vol. 71, Jan. 12, pp. 33–39; Jan. 19, pp. 60–64). By reference to the results of tests of the bending of the stays supporting the coke-side walls of a battery of ovens, the author first indicates the magnitude of the stresses occurring in the walls, and their effect on the structure. He then discusses the structure of silica bricks and the transformations which occur in them. Next, he gives consideration to the behaviour of silica bricks in coke-oven operation, and concludes with a review of points to be considered in selecting and handling materials for the construction of coke-ovens.

Some Observations Concerning the Deposition of Carbon in Blast-Furnace Bricks Causing their Destruction. P. J. Holmquist. (Jernkontorets Annaler, 1934, vol. 118, pp. 519–529). At Svartå, in Central Sweden, the deposition of carbon within the brickwork of a blast-furnace had caused severe damage, within a zone between 4·1 and 8·1 m. from the top. It was found that graphite nodules had been deposited in the bricks, causing them to split. The bricks originally contained some carbon, disseminated as inclusions; quantities of iron oxide were also present. It is suggested that the concentration of the carbon into rounded aggregates occurs by the catalytic action of the iron oxide; hence, carbon in the bricks and Fe_2O_3 in the bond should be avoided.

Experiences with Special Bricks in Open-Hearth Furnaces. F. W. Morawa. (Stahl und Eisen, 1935, vol. 55, Feb. 21, pp. 201–206). The author gives an account of the operating results obtained with a series of special refractory bricks in open-hearth furnaces, and in particular he discusses experiences of the use of magnesite bricks of different varieties and also chromite bricks from various sources with varying properties. On the basis of a comparison of the wear properties, durability and costs of the special bricks with those of silica bricks, he discusses the economy of the use of these bricks, and also other special bricks such as chrome-magnesite, "rubinit," and "magnesidon" bricks, in the construction of open-hearth furnaces.

Experiences with Modern Highly Refractory Bricks for Open-Hearth Furnaces. A. Heger, A. Sonntag, and M. Leineweber. (Stahl und Eisen, 1935, vol. 55, Mar. 7, pp. 265–271). Since October, 1932, the Röchling Steelworks at Völklingen (Saar) have been carrying out experiments with highly-refractory bricks of modern type in the lining of open-hearth furnaces, with the

object of increasing the furnace life (as compared with that of ordinary silica linings), raising the output of the furnace and lowering the cost of production of the steel. Details of the refractories used and their characteristics, and the results of the experiments and their influence on the furnace operation are set out in full.

Comparison of Used Silica Brick from Insulated and Uninsulated Basic Open-Hearth Roofs. F. A. Harvey. (Journal of the American Ceramic Society, 1935, vol. 18, Mar., pp. 86–94). Samples of silica brick from the roofs of two basic open-hearth furnaces, one insulated, the other uninsulated, were examined chemically and petrographically after a full campaign. The insulated brick showed three colour zones, similar to the first three zones of the uninsulated refractory; the latter, however, showed nine zones in all. The zoning probably corresponds to the temperatures which obtain. In contrast to the uninsulated brick, in the insulated brick no zone of weakness was apparent.

Some Notes on the Use of Silica Refractories in Open-Hearth Furnaces. E. Craddock and E. M. Myers. (Cleveland Institution of Engineers, Feb. 4, 1935: Iron and Coal Trades Review, 1935, vol. 130, Feb. 8, p. 251). The authors discuss the requirements of silica bricks for open-hearth furnace construction. The resistance of silica bricks to high temperatures, spalling and slag attack are dealt with. It is pointed out that a brick in which unconverted quartz predominates has peculiar advantages in open-hearth roof construction.

The Lining of High-Frequency Furnaces. (Montanistische Rundschau, 1935, vol. 27, Jan. 16, pp. 1–3). The article gives an outline of experience in English steelworks practice in the lining of high-frequency furnaces.

Care of Cupola Refractories. C. E. Bales. (American Refractories Institute: Foundry, 1935, vol. 63, Jan., pp. 44, 48). A brief discussion of various factors influencing the life of cupola linings.

Refractories in the Foundry. H. C. Biggs. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, May 23, pp. 351–354). The author reviews the characteristics of the refractories—chiefly fireclay—which find use in the foundry. The factors which affect the performance of these refractories in service—such as resistance to high temperature, spalling, slag attack and excessive volume changes—are considered in turn; rammed linings are also dealt with. The behaviour of rammed and bricked linings and of bonding material, under service conditions, is analysed.

Insulating Refractories. W. M. Hepburn. (Journal of the American Ceramic Society, 1935, vol. 18, Jan., pp. 13–17). A number of applications are enumerated, including annealing

furnaces, walking-beam furnaces, muffle furnaces, and so forth. The author examines the salient characteristics of insulating refractories and the savings made possible by their use.

Physical Properties of Some Insulating Brick. W. C. Rueckel. (Journal of the American Ceramic Society, 1935, vol. 18, Jan., pp. 18–22). Results are given of an investigation into the properties of a number of insulating bricks. The properties determined included bulk density, porosity, strength, shrinkage, deformation, and resistance to spalling; a study was also made of permeability.

Light-Weight Cellular Brick made for Furnace. T. E. Wood. (Iron Age, 1935, vol. 135, Feb. 7, pp. 26–28). A brief description is given of the manufacture of insulating brick at the plant of the Armstrong Cork and Insulation Co., Beaver Falls, Pa. Bricks of light weight and low thermal conductivity are produced from diatomaceous earth, which is pulverised and mixed with ground cork and clay. During firing the cork is burned out, leaving air cells which increase the insulating qualities of the bricks.

Glass Silk in Heat Conservation. (Fuel Economist, 1934, vol. 10, Nov., pp. 596–599). Brief particulars are given of the production and properties of glass silk, and its use as an insulating material.

Insulation Against Heat Losses. (Fuel Economist, 1935, vol. 10, Jan., pp. 680–682). The properties of some modern heat insulating materials and their application are discussed.

Insulation of Open-Hearth Reduces Time of Heats. G. Soler and E. E. Callinan. (Steel, 1935, vol. 96, Apr. 15, pp. 62–66). A discussion of factors to be considered in the selection of insulating materials for open-hearth furnaces.

Heat Insulation of Open-Hearth and Electric Steel Furnaces. S. Wohlfahrt and O. Ell. (Jernkontorets Annaler, 1934, vol. 118, pp. 447–474: Stahl und Eisen, 1935, vol. 55, May 30, pp. 590–591). The authors give the results of practical experiments on open-hearth and electric furnaces, which indicate the economies in heat that can be effected by the correct insulation of furnace parts.

High Temperature Insulation for Industrial Furnaces. N. A. Humphrey. (Heat Treating and Forging, 1934, vol. 20, Oct., pp. 509–511; Nov., pp. 559–562; Dec., pp. 612–616). The author sets forth the fundamentals of high temperature insulation in a form useful to the furnace designer for the selection of proper insulating materials.

Silicon Carbide Serves as Heat Exchange Medium. H. L. Read and F. L. Fritsche. (Steel, 1935, vol. 96, Feb. 25, pp. 39–41). The authors discuss the use of silicon carbide recuperators for reheating furnaces and describe those properties of silicon carbide which render this material suitable for the construction of recuperators. The arrangement of a gas-fired reheating furnace equipped with a two-pass silicon carbide recuperator is shown.

FUEL.

PROPERTIES, PREPARATION, MANUFACTURE, AND USES.

FUEL TECHNOLOGY.

Foundations, Development and Examples of Thermotechnological Calculations. Part I.—Foundations and Development of the Formulæ in Material Balances. H. Schwiedessen. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Dec., pp. 231–238). The author has collated in the simplest and clearest possible form the relations (long known and often quoted) for the calculation of thermotechnological quantities. As the basis for his calculations he no longer uses the usual data of composition, such as elementary analysis, gas analysis, and chemical formulæ, but employs the elements in proportions by volume. This has the advantage that all formulæ developed are valid for all the three states of existence of the fuel. From material balances for theoretical, complete and incomplete combustion, he works out formulæ for the air requirements, air consumption and waste-gas volume; also, from a further material balance he develops formulæ for checking the accuracy of the analyses. Account is also taken of the effects of changes in the material heated (decarburisation, loss by burning, deoxidation, drying) by means of special formulæ.

Principles, Development and Examples of Thermotechnological Calculations. Part II.—Examples and Summary of the Formulæ. H. Schwiedessen. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Feb., pp. 329–336). Formulæ previously developed from material balances are explained by means of mathematical examples and are amplified by two special examples. At the end of the paper the most useful formulæ for calculating the dry waste-gas volume, the moist waste-gas volume, the amount of air required, the amount of excess air and the air factor are summarised.

The Effect of Mixing Coals on the Ash Fusion Temperature of the Mixture. T. G. Estep, H. Seltz, H. L. Bunker, jun., and H. S. Strickler. (Mining and Metallurgical Investigations, 1934, Co-operative Bulletin No. 62). The authors report the results of an investigation of the effect of mixing coals on the ash fusion temperature of the mixture. A correlation of softening temperatures and ash analyses was also established.

Graphical Determination of the Moisture Content of Waste Gases from the Combustion of Coal. M. Deladrière. (Chaleur et Industrie, 1934, vol. 15, Nov., pp. 321–324).

The Combustion of Coke. R. A. Mott. (Coke-Oven Managers' Association, Mar. 21, 1935: Gas World, 1935, vol. 102, Apr. 6, Coking Section, pp. 9–15: Colliery Guardian, 1935, vol. 150, May 31, pp. 989–991). The author discusses a number of factors influencing the combustion of coke, and draws attention to the importance of pore surface and external surface area.

Study of Flame. Importance of the Theoretical Temperature of Combustion. Damour. (Chaleur et Industrie, 1934, vol. 15, Oct., pp. 260–261).

Calculation of Theoretical Temperatures of Combustion and the Influence of Radiation on the Heating of Furnaces. C. Le Chatelier. (Chaleur et Industrie, 1934, vol. 15, Nov., pp. 329–332). The author puts forward a new definition for the theoretical temperature of combustion; he also comments briefly on the influence of radiation on the heating of furnaces. In an appendix he gives an example of the method of applying the calculation of the radiation from clouds of dust to the case of luminous flames in a furnace.

Remarks on the Transmission of Heat by Radiation. G. Bruhat. (Chaleur et Industrie, 1934, vol. 15, Nov., pp. 332–335). The author discusses briefly the thermodynamics of the following subjects: (*a*) The transmission of heat by radiation across a gaseous layer; (*b*) the transmission of the energy produced in the interior of a gaseous mass; and (*c*) the cooling of a gaseous mass.

Outline of a Mathematical Study of the Radiation from a Cloud of Dust. H. Malcor. (Chaleur et Industrie, 1934, vol. 15, Nov., pp. 335–337). The thermodynamics of heat radiation from a cloud of dust are dealt with briefly.

Thermal Radiation of Incandescent Gases and Flames. Ribaud. (Chaleur et Industrie, 1934, vol. 15, Oct., pp. 262–265). The author discusses flame constitution and temperature, Kirchoff's radiation law, the absorption of light by gases, spectral radiation curves of incandescent gases, the direct measurement of the total emissivity of a gas and the temperature of radiation, and the effect of solid particles in a flame on the emissivity.

Radiation from Luminous and Non-Luminous Natural Gas Flames. R. A. Sherman. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 177–185). The author presents details of experiments on luminous and non-luminous flames. A gas-fired furnace was used, and measurements of radiation and temperature were carried out. He concludes that luminous and semi-luminous flames are less efficient than non-luminous flames; but with the former a more uniform

temperature over the length of the furnace is attainable—herein lies the advantage of such flames.

Some Notes on Heat Transmission. E. F. Spanner. (Institute of Marine Engineers, Jan. 8, 1935). The author surveys the main factors contributing to the efficiency of heat transmission in boilers. Diagrams are included which indicate the extent to which economy can be effected by utilising waste heat, even of a very low grade.

Heat and Cold Insulation.—A New Field of Application for Sheet Steel. J. F. Shadgen. (Iron Age, 1935, vol. 135, Jan. 17, pp. 8–14). The author discusses the part played by radiation in heat transfer and deals with the use of thin metal sheets with low emissivity values as insulators.

Metallic Insulators are Effective Heat-Ray Traps. J. F. Shadgen. (Iron Age, 1935, vol. 135, Feb. 14, pp. 10–16). The author presents information relating to the use of steel surfaces of low emissivity value for insulating purposes.

The Influence of Humidity on the Physical State of Gases. M. Steffes and R. Welter. (Chaleur et Industrie, 1934, vol. 15, Oct., pp. 266–268). The authors discuss the physics of gases and gas mixtures under the following headings : The perfect gas equation ; mixtures of gas and vapour ; physical condition of water vapour ; hygrometric conditions of gases ; reduction of the volume of a moist gas to the normal dry condition ; and calculation of the density of a moist gas.

The Loeffler System of Steam Production. S. McEwen. (Journal of the Institute of Fuel, 1934, vol. 8, Dec., pp. 87–98). The author surveys the main features of the Loeffler high-pressure steam generating system. Evidence derived from experience of Continental operating units is put forward to establish the superiority of the system. A marine unit is dealt with, and a typical pump and several boiler installations are described and illustrated.

Care of Modern Steam Generating Plant from the Water Side. R. J. Glinn. (Institution of Mechanical Engineers, Jan. 25, 1935 : Engineer, 1935, vol. 159, Feb. 1, pp. 131–134). In this article the factors which lead to boiler failure are examined. It is pointed out that troubles attributable to feed-water arise from the chemical nature of the water. Excess alkalinity may promote caustic embrittlement ; acidity, on the other hand, may give rise to corrosion. Scale formation may be reduced by proper attention to the concentration of dissolved solids. Scale is a common cause of failure ; examples of failures due to corrosion and scale are cited.

Super-Imposed Steam Turbine-Generator Plants for the Steel Mill. A. G. Darling. (Iron and Steel Engineer, 1934, vol. 11, Dec., pp. 469–477). The use of high-pressure steam generators

to replace existing low-pressure plant in steel mills is the theme of this paper. The author suggests the use of steam at a pressure of 1,200 lb. per sq. in. for the main power and process requirements, with auxiliary boiler equipment at 200 lb. per sq. in. to take care of the peak loads. He examines a number of existing installations, indicates the manner in which high-pressure plant may be substituted for existing units, and sets forth the economies which may be expected. Emphasis is placed on the savings which may be made in the production of electrical energy by the use of high efficiency turbo-generators. The problem of feed-water is dealt with, and the cost of treatment is said to be not excessive. Flow-sheets and operating schedules, comparing the high- and low-pressure systems, are included.

Generation and Utilisation of Electricity in German Iron and Steel Works. H. Euler. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Nov., pp. 197–204). The author presents a statistical study, based on the replies to a questionnaire, of the amounts of electricity generated and utilised in German iron and steel works ; the values for 1929 and for 1932 are taken as representing maximum and minimum figures.

Electricity in the Iron and Steel Industry. W. J. Pool. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 197–201, 206). Increased efficiency in the steelworks often makes it desirable to take power from an outside supply rather than generate it from waste-heat boilers. For constant-speed non-reversing drives the induction motor is highly suitable, but for variable-speed drives d.c. motors are preferable. For auxiliaries either a.c. or d.c. machines may be used. If external power is taken some means must be adopted to correct the low power factor usual in steel plants ; synchronous motors, phase advancers, and condensers may be used.

Thermal Comparison of the Gas Engine and the Steam Turbine. M. Steffes and R. Welter. (Revue Technique Luxembourgeoise, 1934, vol. 26, Nov.-Dec., pp. 138–141). After touching briefly on the factors influencing the cost of the unit of electricity, the authors present two graphs of the consumption of gas and of steam in electric generating plants of a maximum power of 15,000 kw.

The Valuation of By-Product Energy in Ironworks. E. Witting. (Montanistische Rundschau, 1935, vol. 27, Jan. 1, pp. 1–3). The author discusses the utilisation of by-product energy (blast-furnace gas, waste-heat, &c.) produced in one division of an ironworks and consumed in another from the economic point of view, the determination of its true value and the apportionment of the value between the producing and consuming departments.

Theory and Practice of Immersion Heating with Gaseous Fuels. E. B. Dunkak. (Iron and Steel Engineer, 1935, vol. 12,

Mar., pp. 167–172). The author discusses the application of immersion heating and points out its advantages. Complete premixing of the gas and air is essential in this method of heating, which has been applied in tinplate manufacture and in heat treatment with salt baths.

The Basic Principles of Thermotechnological Calculations for Furnaces. W. Heiligenstaedt. (Stahl und Eisen, 1935, vol. 55, Mar. 21, pp. 334–337).

Some Factors Affecting Furnace Heating Practice. R. J. Sarjant. (Iron and Steel Industry, 1935, vol. 8, Jan., pp. 147–149). The author deals with some of the various factors (such as heat storage in furnace walls, the flow of gases in furnaces, and draught losses) which determine the performance of furnaces. Suggestions are made, having for their object the improvement of furnace efficiency.

Factors Affecting the Capacity and Thermal Efficiency of Furnaces. H. Southern. (Metal Treatment, 1935, Spring Number, pp. 17–20, 29). The author states that the fuel consumption during a particular operation depends upon (*a*) the design and construction of the furnace ; (*b*) the weight of the charge ; (*c*) the time-temperature cycle. As an example, a furnace for the treatment of coiled steel strip in pots is cited. The author examines the heat losses through the walls, the heat absorbed by the charge, and hence the thermal requirement per cycle ; he compares the observed results with those to be derived by calculation, and establishes a relation between output and thermal efficiency. Finally, an equation is obtained to describe the relation between the thermal efficiency of the furnace, the weight of the charge, the heat losses, and the conditions of combustion.

Measurement of Large Volumes of Flowing Gas by Means of a Diaphragm in a Thin Partition. Laffargue. (Chaleur et Industrie, 1934, vol. 15, Dec., pp. 365–368). The Verein deutscher Ingenieure have drawn up rules for the measurement of large volumes of flowing gas by means of diaphragms, and these rules were to some extent internationalised at a conference in Milan in 1932. But it was indicated that these rules would not apply in cases where the Reynolds number was less than about 200,000. Now, in blast-furnace works it is a case of measuring thousands of cubic metres of gas circulating in mains of 1 m. to 2 m. in diam., but at velocities which rarely amount to as much as 10 m. per sec. ; this case falls outside the rules mentioned above, for the Reynolds numbers are much lower, and the coefficient of flow may vary very markedly with the velocity. It is this latter case which the author discusses in this article. He recommends the measurement of the coefficient of flow by means of very sensitive Pitot tubes or micromanometers.

The Experiments on the Control Section at the "Wärmestelle Düsseldorf." G. Jungnitz. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Mar., pp. 371–377). The author first discusses the various factors which affect the speed and precision with which any type of control apparatus operates and returns the object controlled to the desired condition. He exemplifies his points by reference to the case of a furnace of which the temperature is controlled by the degree of opening of the gas valve, this being actuated by a thermocouple; the sensitivity and time-lag of the thermocouple, the speed of functioning of the gas valve, &c., all influence the extent to which the temperature will deviate from the desired value before being brought back by the control apparatus. The author then gives an account of experiments made on apparatus for controlling the relative rates of flow of two gases so as to maintain a constant mixture, and on a pressure regulator. The experimental values obtained are recorded, and some practical values are given as examples.

The Basic Laws of Regulation. K. Rummel. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Jan., pp. 281–291). The author presents a summary of researches carried out at the Wärmestelle, Düsseldorf, on the fundamentals of, and the various influences affecting, the functioning of automatic regulators; the subject is dealt with mathematically from the theoretical point of view.

Automatic Control and Use of Fuels in Steel Mill Furnaces. A. J. Fisher. (Iron and Steel Engineer, 1935, vol. 12, Mar., pp. 149–158). The author discusses the utilisation of blast-furnace gas and mixed gas in steel mills, and the importance of automatic control in ensuring maximum efficiency. It is stated that where no gas-holders are available after mixing, blast-furnace gas and coke-oven gas are best mixed by the Iris valve mixing station. The layout of this type of mixing station is illustrated. Graphs are also given showing the flame temperatures of mixed blast-furnace and coke-oven gas with cold air and of blast-furnace gas with preheated air, and particulars are included of the quantities of gas produced from four blast-furnaces making 1,000 tons of pig iron per day with a coke ratio of 0·85. The use of blast-furnace gas in stoves, reheating furnaces and soaking pits is discussed.

Use of Automatic Control on Metallurgical Furnaces. A. J. Boynton. (Iron and Steel Engineer, 1935, vol. 12, Mar., pp. 159–166). The author discusses the present status of automatic control for metallurgical furnaces and describes and illustrates several types of equipment.

Fuel-Fired Furnace Temperature and Atmosphere Control. G. H. Barker. (Metallurgia, 1934, vol. 11, Dec., pp. 29–32). The author compares the salient features of automatic gas control with those of manual control, and pronounces in favour of the

former method. He goes on to discuss the different types of control which are available, and the circumstances in which they are severally applicable. The simple "on and off" control, though apparently crude, is capable of regulation within 5° at 1,000° C., mainly because of furnace lag. Two-position control is capable of finer regulation, whilst three settings give even more satisfactory results. Balancing and floating controllers may be adopted if flexibility and close temperature regulation are both required. Automatic control can be arranged to secure the maintenance of predetermined time-temperature cycles, and to obtain control over the furnace atmosphere.

Photo-Electric Temperature Regulator. B. Lange and E. Voos. (Zeitschrift für technische Physik, 1934, vol. 15, p. 323). The authors describe an apparatus for regulating the temperature of electric resistance furnaces. A thermo-element in the furnace actuates a galvanometer, on to the mirror of which a light beam falls. When the furnace temperature rises above the predetermined value, the rotation of the galvanometer mirror throws the reflected light ray on to a photo-electric cell; this, through the intermediary of a thermionic valve, actuates the control switch and cuts off the current supply.

COAL.

British Coals—Their Analyses and Uses. (Fuel Economist, 1935, vol. 10, Mar., pp. 749–756; Apr., pp. 815–818; May, pp. 874–875). A series of articles giving particulars and analyses of a number of British industrial coals, together with the names and descriptions under which they are marketed.

Action of Solvents on Coal. R. S. Asbury. (Industrial and Engineering Chemistry, 1934, vol. 26, Dec., pp. 1301–1306). The author has made a study of the benzene pressure extraction of Edenborn coal from the Pittsburgh seam. Apparatus and methods are described for the pressure Soxhlet treatment of the coal, the determination of yields of soluble products, and their chemical separation. Reduction in particle size of the coal increases the yields of products. Increased yields result also from heating the coal up to 450° C. in the presence of benzene vapour at high pressures when combined with extraction at 260° C. The products resulting from benzene extraction at 260° C. are largely neutral, with less than 3 per cent. acidic, basic and phenolic materials present. Combined extraction and high-pressure heating result in increases in phenolic and basic materials. The neutral ether-insoluble bodies decrease with rising temperature, indicating the possible formation of phenolic and basic materials from ether-insolubles. With benzene, under the most favourable conditions

slightly less than 30 per cent. by weight of the coal was made soluble. The curves of yield of soluble product *versus* inverse time of extraction indicate that complete dissolution of the coal would be impossible under these conditions.

Investigation on the Analytical Decomposition of Ruhr Coals. H. Winter, H. Mönnig and G. Free. (Glückauf, 1935, vol. 71, Apr. 27, pp. 389–396). A large number of all kinds of coals from the Ruhr were decomposed by the English method into hydro-carbons, resins, humic compounds and structured plant residues. In this respect it appears that the Ruhr coals have a structure similar to that of English coals. In further tests the reactivity of the humins increased to a maximum as the carbon content of the coal decreased, and then decreased again. The potassium permanganate indices of the extracted and of the original coals also increased with the decreasing carbon content. For various reasons the English method does not seem suitable for determining the reactivity of the humins, though for untreated Ruhr coals it does make possible the use of the simple permanganate test to determine the properties of the coal ; the petrographic structure of the coal must, however, be taken into account.

A Study of Durains and Cannel Coals. Wen-Min Chao. (Fuel in Science and Practice, 1935, vol. 14, Mar., pp. 64–80). The nature of durains has been investigated and a study made of the relationship between durains and cannel coals.

Influence of the Material Composition of Coals on their Fusion Characteristics. A. van Ahlen. (Glückauf, 1935, vol. 71, Jan. 19, pp. 68–70). The author presents the results of experiments made on natural coal mixtures to determine the dependence of their softening and decomposition temperatures on the proportions of the structural components present. In order that the different fusion characteristics should be plainly apparent, it was necessary to choose a material in which the structural composition should differ as much as possible ; to this end crude slimes and flotated slimes from a mine were used, and the natural difference in the structural composition was attained by sieving into different grain sizes.

Investigations on the Phosphorus Content of Coal and Coke. E. Hoffmann and H. Lehmkühler. (Brennstoff-Chemie, 1934, vol. 15, pp. 381–386 : Stahl und Eisen, 1935, vol. 55, Jan. 31, pp. 114–115). After discussing the behaviour of phosphorus in the blast-furnace the authors describe their investigation of the distribution of that element in coal, with a view to determining the possibility of effecting a mechanical separation of the phosphates in the coal. While the distribution of the phosphorus was found to be irregular so far as the " age " of the components was concerned, it was noteworthy that the phosphorus content of fusain-rich dust was always the highest. Analyses of sieved

fractions showed that the phosphorus distribution in dull and bright coals varied greatly ; in some tests the bright coal, and in others the dull coal contained more phosphorus. Bituminous shale was also found to be a " phosphorus carrier." Further tests dealt with the separation of the phosphorus by fine sieving, wet-mechanical and dry preparation, and petrographic separation followed by flotation. The choice of the most suitable method was found to depend on the particular coal in question. The difficulties of estimating the phosphorus in coal are discussed.

Blast-Furnace Fuels—Anthracite Coal. R. H. Sweetser. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 611). The fact that anthracite was used in the blast-furnace for over 75 years without its character being well known and its superior qualities being recognised, leads the author to conclude that possibly present-day practice could be much improved by a better understanding of the behaviour of coke in the blast-furnace. It would be worth while to determine whether the superior quality of anthracite pig iron was due to the anthracite alone or partly to the small diameter of the anthracite blast-furnaces.

Modern Developments in Coal Cleaning. V. F. Gloag. (Journal of the Institute of Fuel, 1934, vol. 8, Dec., pp. 108–109).

Influence of the Cleaning Method and of the Fuel Requirements on the Yield from Fine-Coal Washeries. O. Schäfer. (Glückauf, 1935, vol. 71, May 11, pp. 437–445). By means of washing tests and washing curves, the author has determined for a fine fat coal the yield of coking coal with a certain ash content as well as the yield and ash content of boiler coal ; a diagram is presented, from which the rate of steaming can be read off for every value of the sum of the ash plus moisture content. The probable moisture content can be calculated in all cases from the composition of the fine coal and of the boiler coal. From these data the amount of steam that may be raised with the boiler coal produced can be calculated, and the most suitable washing process for the local conditions selected. It is essential that not only the washing but also the boiler plant must suit the coal produced, the internal consumption and the conditions of disposal.

Results of Selective Coal Flotation Based on the Chemistry of Coal. J. Pöpperle. (Glückauf, 1935, vol. 71, Feb. 2, pp. 101–105). A new process of coal flotation was described in an earlier paper (*see* Bierbrauer and Pöpperle, Journ. I. & S.I., 1934, No. II. p. 510) ; in the present paper the author gives the results of tests on the method carried out on a number of coal samples. The degree of separation was determined by methods based on the chemistry of coal. It appeared that by carrying out the flotation in a suitable manner, the coal could be separated into chemically reactive and inert fractions. The

utilisation of the inert product in the dust-injection engine is discussed.

The De Vooys Process of Coal Cleaning. R. A. Mott. (Colliery Engineering, 1935, vol. 12, Feb., pp. 47–52). The author describes the De Vooys gravity separation process, which uses a bath of heavy medium composed of a mixture of barytes (barium sulphate) and clay. The heavy medium is a stable suspension which does not require any upward current for its maintenance, and the losses of barium sulphate are reduced to about 3 lb. per ton of coal cleaned. The process was developed at the Sophia-Jacobia Colliery to treat German anthracite which was unsatisfactorily washed by ordinary jig washers.

The Cleaning of Coal, in Germany, by Means of a Dense Solution. C. Berthelot. (Génie Civil, 1934, vol. 105, Dec. 29, pp. 593–599). The author discusses the theory and practice of the De Vooys method of wet-cleaning coals, and describes the plant at the Sophia-Jacoba Colliery near Aachen.

Industrial Coal Preparation by Means of Heavy Liquids. C. Hanot. (Revue Universelle des Mines, 1935, vol. 11, Apr., pp. 185–193). After briefly describing the Lessing and the Chance methods of cleaning coal, the author gives particulars of a method devised by De Vooys.

The "Static" Dry Washer at Wearmouth Colliery. T. C. Futers. (Colliery Guardian, 1934, vol. 149, Oct. 19, pp. 707–711). The general arrangement and equipment of this coal-cleaning plant are described and illustrated.

The Cleaning of Coal. P. Fox-Allin. (Iron and Coal Trades Review, 1935, vol. 130, Jan. 11, pp. 58–59). Various systems of coal cleaning are discussed, including the questions of dedusting and slurry treatment. The directions in which developments have taken place during the past year are indicated.

The Dry Cleaning of Steam Coal in South Wales. W. B. Davies. (Proceedings of the South Wales Institute of Engineers, 1935, vol. 51, No. 1, pp. 21–76). The introduction of mechanical appliances at the Cymmer Colliery for the winning of coal resulted in an increase in the percentage and ash-content of the smaller sizes. The author discusses briefly the factors which governed the selection of the necessary plant for the cleaning of this coal, and describes the plant which was finally installed.

The Comminution of Coals during Dedusting in Air Separators. A. Pelzer. (Glückauf, 1934, vol. 70, Dec. 8, pp. 1172–1175). The author points out the considerable breaking-down of particle size undergone by coals during dedusting in air separators, and indicates the need for taking account of this comminution in calculating the efficiency of separation, although the operating and other conditions often make it difficult to obtain the necessary data.

The Conditioning of Washery Water : Flocculation. W. E. Raybould. (South Staffordshire and Warwickshire Institute of Mining Engineers, Dec. 10, 1934 : Colliery Guardian, 1934, vol. 149, Dec. 14, pp. 1094–1096 ; Dec. 21, pp. 1140–1141). It is shown that the correct treatment of washery water to prevent contamination by colloidal material consists of : (*a*) Conditioning the water, by means of electrolytes, &c., to reduce the breakdown of clay particles, thereby allowing them to be discharged with the refuse ; and (*b*) flocculation of the residual colloids to ensure rapid settling in the cone and to obtain a high filtration rate of the effluent. Although the presence of certain dissolved solids appears to be beneficial in inhibiting the breakdown of clay particles, further investigation is required to ascertain the most suitable reagent. The evidence with regard to the merits of lime in this direction is inconclusive. The value of magnesium salts in conjunction with lime is demonstrated.

The Clarification of Washery Water. C. W. H. Holmes. (Colliery Engineering, 1935, vol. 12, Feb., pp. 40–42, 58 ; Mar., pp. 80–82 ; Apr., pp. 133–136). A discussion of the flocculation and filtration of the various solids present in coal washery waters.

The Flocculation of Slurries. D. T. Davies and E. T. Wilkins. (Fuel in Science and Practice, 1935, vol. 14, Feb., pp. 51–55). The authors describe some small-scale experiments on the clarification of coal washery water using glue as a flocculent.

The Relative Grindability of Coal. H. J. Sloman and A. C. Barnhart. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 773–779). The author introduces a method of assessing the grindability of coal depending on the crushing action of a steel roller on an inclined plate upon which the sample is spread. The results of a number of tests are furnished ; they are also correlated with grindability indices obtained by other methods.

Burning Characteristics of Pulverised Coals and the Radiation from their Flames. R. A. Sherman. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 401–409). An investigation was undertaken to establish the combustion characteristics of four American coals used for pulverised fuel. The relations between the type of coal, rate of combustion, fineness of pulverisation, and heat radiation were examined. The main conclusions are : That fineness of grinding becomes increasingly important with decrease in combustion space ; that augmented furnace temperature increases the rate of burning ; that the temperature and radiation are affected by the fineness of grinding, air supply and rate of firing ; and that the emissivity of the flame is only influenced by the type of coal.

The Propagation of a Zone of Combustion in Powdered Coal : The Composition of the Products of the Oxidation. H. E. Newall.

(Fuel in Science and Practice, 1935, vol. 14, Feb., pp. 34–42). The author has studied the propagation of a zone of combustion through a heap of finely-divided coal in a confined space with a controlled supply of air or atmospheres containing various percentages of oxygen passing over the coal. Combustion was carried out in tubes of different diameters through which a current of air was passed in the opposite direction to the wave of combustion. The bright and dull coal from the Parkgate seam were used and the compositions of the gaseous products and solid residues were determined. The rate of combustion decreased with decreasing rate of air flow, and if the supply fell below 1 litre per hr. the initial oxidation induced in the coal would not proceed throughout the mass. With a tube of 2·5 cm. diam., the composition of the oxidation product and the percentage of oxygen in the effluent gas were constant for the rates of air flow used. This percentage of oxygen (11·2 per cent. in the case of the bright coal and 12·5 per cent. with the dull coal) was the minimum percentage in which propagation of a zone of combustion would proceed.

Mechanism of Combustion of Pulverised Coal. M. A. Mayers. (American Institute of Mining and Metallurgical Engineers: Iron and Coal Trades Review, 1935, vol. 130, Feb. 1, p. 218).

Pulverised Fuel Firing. (Fuel Economist, 1935, vol. 10, Jan., pp. 683–688). A review of recent developments in the firing of pulverised fuel.

Pulverised Fuel in the Metallurgical Industry. J. H. Mahler. (Proceedings of the South Wales Institute of Engineers, 1935, vol. 51, May 10, pp. 79–97). Pulverised fuel has many advantages, such as complete combustion, flexibility, reduction in cost of firing and cost of fuel. Most of the world's copper production is smelted with this form of fuel. Another application is air melting furnaces for roll making. Pulverised fuel may be profitably employed for the firing of reheating furnaces, and especially for forgings. The system can be successfully applied to annealing furnaces for malleable iron, steel plate and strip and hot pressings. Of the firing methods employed, the unit system would appear preferable to the storage system.

Optical Apparatus for Dust Analysis. E. Stach. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Apr. 27, pp. 513–516). Various types of microscope for the examination of powders, such as coal dust, &c., are illustrated and described.

The Testing of the Suitability of Briquette Pitch and its Importance in the Briquetting Process. W. Reerink and E. Goecke. (Glückauf, 1935, vol. 71, Jan. 26, pp. 77–85; Feb. 2, pp. 105–114).

COKE.

The Coking Industry. Its Progress and Development during 1934. R. A. Mott. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 155–158). The author reviews post-war economic conditions in the coke industry and the revival of demand in 1934.

Coke-Oven Installation at Cargo Fleet Iron Works. (Iron and Coal Trades Review, 1934, vol. 129, Dec. 7, pp. 890–892). The constructional arrangement of the Gibbons-Kogag coke-oven is illustrated and described, and particulars are given of the coking plant of the Cargo Fleet Iron Works. This consists of 64 Gibbons-Kogag regenerative combination ovens, designed for heating with coal gas or blast-furnace gas. The ovens are fitted with superimposed flues to minimise so far as possible the decomposition of the hydrocarbons which takes place in the free space at the top of the oven chamber and thus to effect an increase in the yield of benzol.

Cargo Fleet Iron Co., Ltd. (Colliery Guardian, 1935, vol. 150, Jan. 11, pp. 59–62). An illustrated account is given of the coking plant at these works.

Coke-Oven Plant at Cargo Fleet Ironworks. (Engineering, 1935, vol. 139, Mar. 8, pp. 251–252). An illustrated account is given of this coke-oven plant.

The Coking Plant of the Yorkshire Coking and Chemical Co. at Glass Houghton. J. Sinclair. (Colliery Guardian, 1935, vol. 150, Mar. 1, pp. 381–384 ; Mar. 8, pp. 427–430).

Coke-Oven Installation of the South African Iron and Steel Industrial Corporation, Pretoria. (Iron and Coal Trades Review, 1935, vol. 130, Mar. 29, pp. 529–532). The coking installation at the new Iscor Works of the South African Iron and Steel Industrial Corporation comprises Becker ovens, by-product recovery plant, coal handling, blending and crushing plant, and coke-screening plant, together with a T.I.C. tar distillation plant. The coke-oven plant consists of 57 ovens fired by blast-furnace gas.

The Mechanical Equipment of Coke-Oven Installations. H. C. Wood. (Coke-Oven Managers' Association, 1935, Mar. 23 : Gas World, 1935, vol. 102, Apr. 27, pp. 416–425 : Iron and Coal Trades Review, 1935, vol. 130, Apr. 5, pp. 575–578 ; Apr. 12, pp. 629–630 ; Apr. 19, pp. 658–660). The different mechanical units employed in the production of coke are described in some detail. The types of coal charging car are fully dealt with, and considerable attention is devoted to modern coke pushers. These usually perform several operations, such as levelling the charge, discharging the coke, handling the oven doors. An account is also given of the combined door extractor and coke guide machine, the coke-quenching car, the locomotive for the coke cars, the

gas and air reversing gear, and the numerous control units and protective devices. Examples of gear used in plants now operating are described.

Coking the Barnsley Seam. R. A. Mott and R. V. Wheeler. (Midland Institute of Mining Engineers, Dec. 6, 1934: Colliery Guardian, 1934, vol. 149, Dec. 14, pp. 1089–1092). The authors have investigated the coking properties of coal from the Barnsley seam in the South Yorkshire district. The quality of the coke made from the small coal of the Barnsley seam depends mainly on the rank of the coal, on the quantity of durain it contains, and on its size. When the Barnsley seam is of the lowest rank, it is commercially non-coking if used alone, but if blended with a coal of high swelling power, it can yield excellent coke; considerable proportions can be so blended. It is possible that, as knowledge of the manner of formation of coke increases, Barnsley coal of the lowest rank can be so treated as to yield good blast-furnace coke.

Some Notes on the Examination of Coals for the Production of Blast-Furnace Coke. J. L. Lambert. (Coke-Oven Managers' Association, Mar. 2, 1935: Gas World, 1935, vol. 102, Apr. 6, Coking Section, pp. 16–18). The author describes laboratory coking tests on several blends of coal for the purpose of determining their suitability for the production of blast-furnace coke. He also presents the results of tests carried out in an experimental oven at the Margam Works.

Relation of Microscopic Composition of Coal to Chemical, Coking, and By-Product Properties. G. C. Sprunk and R. Thiessen. (Industrial and Engineering Chemistry, 1935, vol. 27, Apr., pp. 446–451). The authors deal with the appearance and behaviour of certain coals mined in the U.S.A. The constituents present (anthraxylon, or vitrain, fusain and attritus) are discussed in relation to the properties of the coals.

The Value of the Determination of the Coking Index of Coals. A. van Ahlen. (Glückauf, 1934, vol. 70, Dec. 8, pp. 1178–1180). The author discusses criticisms that have been made regarding the utility of the various methods of determining the coking index and the conclusions that can be drawn from the results obtained. He emphasises that the estimation of the coking index is simply a works method, by which the coke-oven operator can judge of the characteristics of his own coals and coal mixture.

Determination of Gas, Coke and By-Products of Coal. W. A. Selvig and W. H. Ode. (Industrial and Engineering Chemistry, Analytical Edition, 1935, vol. 7, Mar. 15, pp. 88–93). The authors have carried out two small-scale, laboratory, high-temperature assay tests and one low-temperature assay test on a number of coal samples for the determination of the yields of gas, coke and by-products. Check limits were established for duplicate determinations on the same coal by the same

laboratory. The yields of gas, coke and by-products given by the laboratory tests were correlated with the yields obtained by the BM-AGA carbonisation test, and it was found that the factors for converting the yields obtained by the small-scale laboratory tests into those obtained by the carbonisation test varied appreciably with different coals.

The Assessment of the Carbonising Properties of Coal. G. A. Dummett and R. Stancey. (Coke Oven Managers' Association, Oct. 19, 1934 : Gas World, 1934, vol. 101, Nov. 3, Coking Section, pp. 14–17 ; Dec. 1, Coking Section, pp. 8–10). The authors have studied the effect of certain variables on the coke-forming properties of coals, including the effect of blending with coke dust, wash oils, and other materials, and the effect of fineness of crushing.

Investigation of Bright and Dull Coals from Upper Silesian Seams. K. Drees and G. Kowalski. (Brennstoff-Chemie, 1934, vol. 15, p. 221 : Fuel in Science and Practice, 1934, vol. 13, Dec., pp. 366–370 ; 1935, vol. 14, Jan., pp. 18–23). The authors present the results of an investigation of the coking properties of banded coal samples from the Hohenzollern Mine, Upper Silesia.

Coking Tests on Stored Fine Coal. P. Michaelis. (Glückauf, 1935, vol. 71, May 4, pp. 413–423). Washed fine coals stored in the open undergo slow chemical reactions with the oxygen of the air (slow combustion), which are indicated by a loss of moisture and a rise of temperature. These chemical changes can be followed by laboratory coking tests. The swelling properties and tar yield decrease in proportion to the duration and mode of storage, the decrease being related directly to the heat evolution and the extent of drying. The water present in the coal favours its oxidation, yet it offers a certain resistance to the course of the chemical reactions. As the storage period is prolonged, fat coals develop more and more the coking characteristics of a semi-bituminous coal, and therefore can be used for blending with gas-rich swelling coals. The blending of stored fat coals with the same coals in the " fresh " condition has been used at the de Wendel Colliery for some time with success.

Gas- Coke- and By-Product-Making Properties of American Coals and Their Determination. A. C. Fieldner and J. D. Davis. (U.S. Bureau of Mines, 1934, Monograph No. 5). The usual small-scale gasification tests are not sufficiently comparable with large-scale experiments to justify full reliance being placed upon them. To remedy this a small pilot plant was devised, and complete carbonisation tests were carried out on 30 different coals, at temperatures ranging from 500° to 1,100° C. The coals were also subjected to chemical analysis, petrographic examination, assay distillation and the determination of the agglutinating index

and plastic properties. The retorts used in the carbonising tests were 13 in. in diam. and 26 in. high, of sheet steel, holding a charge of from 85 to 105 lb. They were either gas-fired or electrically heated. Some 18-in. diam. retorts were also employed. The by-products were collected by means of a condensing, tar-precipitating and scrubbing train. The yields obtained from the test retort and from commercial plants are compared ; in addition, a study of the relation between the chemical and physical examination of coals and their coking properties is made, and it is concluded that most of the special laboratory tests have little practical value.

The Drying of Coking Coals. R. V. Farnham. (Colliery Guardian, 1934, vol. 149, Dec. 7, pp. 1043–1045). The author discusses the drying of coal and its influence on carbonisation. It has been suggested by competent authorities that a coal with a moisture content of 7 per cent. is ideal for carbonising at high temperatures. Bulk density of the charge is influenced considerably by the moisture content, and experiments have shown that an increased bulk density of coal is obtained with only 2 per cent. of moisture as compared with 7 per cent. The effect upon the coking time of reducing the moisture content of the coal to 2 per cent. is most marked. The estimated capital cost and running charges for a typical drying installation are shown.

Carbonisation of Coal. W. B. Warren. (Industrial and Engineering Chemistry, 1935, vol. 27, Jan., pp. 72–77). The author reports the results of a study of the carbonisation of a typical coking coal at rates of heating ranging from 0·7° to 21·8° C. per minute to maximum temperatures of 540°, 700° and 1,000° C. With uniform rates of heating throughout the ranges studied, the yields of tar increased with increase in rate of heating at the expense of gas and coke yields. It is concluded that the mechanism of coking involves competition between distillation and decomposition processes, and that differences in the magnitude of their temperature coefficients are responsible for the increase in tar yield as the rate of heating is increased. The solvent action of the liquid products of carbonisation prior to distillation or decomposition may be an important factor in determining both the yields of the various products and their properties.

Internal Gas Suction in Coking Practice. (Fuel Economist, 1934, vol. 10, Nov., pp. 580–583). Particulars are given of the Still process for the removal of primary volatile distillation products from coke-ovens, and previous attempts on the same lines are briefly reviewed.

High-Temperature Carbonisation of Coal. J. D. Davis and S. Auvil. (Industrial and Engineering Chemistry, 1935, vol. 27, Apr., pp. 459–461). Experiments were undertaken to ascertain the effect of the free space above the charge on the yields and

properties of the liquid and gaseous products. An increase in free space improved the yield of light oil, benzene, pitch and aromatic solids, and diminished the yield of neutral oils, aromatic liquids and tar acids.

Methods of Increasing the Benzol Yield during Coking. L. Nettlenbusch and A. Jenkner. (Glückauf, 1934, vol. 70, Dec. 8, pp. 1165–1172). After describing methods suggested in recent years for improving the benzol yield from the coking process, the decomposition reactions taking place in the coke-oven are considered in detail. From laboratory experiments it appears that destructive decomposition of the benzene hydrocarbons present in the coke-oven gas does not set in below 750°, even in the absence of protective steam, whereas the breakdown of the unsaturated compounds begins at as low a temperature as 500°. As, however, in works operation with supplementary cracking, some decomposition of tar occurs with the production of benzene hydrocarbons, the losses observed in the laboratory are more or less cancelled out ; in fact, by keeping the cracking temperature within certain limits the benzol yield may even be raised. Tests undertaken in a coke-oven plant showed that, with the fat coals in question, careful treatment of the distillation gases did not result in any increase of the benzol yield. Nevertheless, laboratory tests demonstrated that by simultaneously cracking the distillation gases the yield could be increased, and that the maximum was attained by employing a cracking temperature of 800°–850°. In similar tests made on an operating scale, supplementary cracking raised the benzol yield by 15 per cent. above that obtained by the normal process, while the amount of tar produced decreased by 8 per cent.

In practice, the maximum benzol yield can be obtained irrespective of variations in the coking time, by building roof gas flues which can be heated independently of the coke-oven so as to give the optimum cracking conditions. In this way some allowance can be made for the characteristics of the various coals used and of the operating conditions, the gas being passed through the usual gas collector or the superheated gas flues as required.

Experiences with the Roof Gas Flue in Coke-Ovens. F. Goldschmidt. (Glückauf, 1935, vol. 71, Feb. 9, p. 138). The author discusses his experience in the use of gas flues in the roof of coke-ovens and their influence on the products contained in the coke-oven gas.

A New By-Product from Coke-Ovens. G. E. Foxwell. (Colliery Engineering, 1934, vol. 11, Nov., pp. 372–374, 382). The author describes the arrangement and use of the Goldschmidt channel in coke-ovens, and considers the possibilities of this and other

systems in effecting an increase in the production of lighter oils for subsequent conversion into motor spirit.

The Thermal Processes during Coking. W. Litterscheidt. (Glückauf, 1935, vol. 71, Feb. 23, pp. 173–181). On the basis of a large number of temperature measurements made in coke-ovens and in a laboratory coking retort, the author discusses the flow of heat during the coking process and the influence on it of various factors such as the bulk density, moisture content and degree of fineness of the coal charge. On the basis of these theoretical considerations the author draws conclusions regarding the coking process, the throughput of a coke-oven and the amount of heat required for coking.

Studies of Coke Formation. XII.—The Coking Properties of Durain. R. A. Mott. (Fuel in Science and Practice, 1934, vol. 13, Dec., pp. 356–365). It is misleading to state that durain is non-coking, for lump durain, even from a coal of low rank, will give a residue of regular porous structure which is the outstanding property of "coke." Durain is, however, much less strongly swelling than bright coal and rarely swells sufficiently to enclose all the free space in a charge of loose particles, and a pebbly structure, in which the shape of the original particles is evident, may be produced. In certain durains of moderately high rank, a very fast rate of heating causes sufficient swelling for the shape of the individual particles to be lost. In durain of low rank, fine grinding enables a more firmly agglomerated coke to be made from a charge of loose particles. Blending with bright coal from the same seam is also effective in causing good agglomeration, the necessary percentage of bright coal increasing the lower the rank of the durain. A coking slack consisting of 70 per cent. of bright coal and 30 per cent. of hards is, in effect, a blend or mixture of two types of coking coals, the dull coal being in some respects equivalent to a bright coal of lower rank. Such a mixture can be used to make a satisfactory coke in coke-ovens even when the bright coal is of relatively low rank, *e.g.*, 83 per cent. carbon. It is important, however, that the durain should be well mixed with the bright coal and that the slack should be finely crushed (say, 100 per cent. through $\frac{1}{4}$-in., 90 per cent. through $\frac{1}{8}$-in.) to avoid an undue concentration of durain in the coarser sizes and its segregation in one part of the oven.

Coke Plant Still Waste is Clarified by New Process. B. K. Price. (Steel, 1935, vol. 96, Jan. 28, pp. 35–36). An outline is given of a new process developed by the Lancaster Iron Works, Lancaster, Pa., for the removal of free solids and phenols from still waste liquor in by-product coke-oven plants.

Processing of Solid and Liquid Hydrocarbons in the Coal, Oil and Gas Industries, with Reference to Developments at Corby. A. Fisher. (Institute of Fuel, Apr. 10, 1935: Iron and Coal

Trades Review, 1935, vol. 130, Apr. 12, pp. 617–619). The paper refers to the Knowles process, in which D-shaped ovens, with flat hearths heated from below, are employed for: The direct coking of coals; the processing of petroleum residues; the manufacture of pitch coke; the production of rich gas from liquid residues. The process may also be applied to the coking of non-coking coals; a suspension of pulverised coal in petroleum oil is carbonised, the distillates being simultaneously cracked. The system is stated to be very flexible.

The "Coal in Oil" Process of Low-Temperature Distillation of Coal. A. Thau. (Glückauf, 1935, vol. 71, Jan. 5, pp. 10–15). The author describes the "Coal in Oil" process of low-temperature carbonisation, the material balance, the condition of the coke, the coke and gas produced and the pressure-cracking of the oils, and gives some notes on the plant erected at the steelworks of Messrs. Stewarts and Lloyds, Ltd., at Corby. The finely-ground coal is mixed to a paste with oil, and is fed into the special coke-ovens through pipes under pressure. The Knowles coke-oven is heated through the sole, which measures 10 m. long and 3 m. wide; the side walls are low and carry an arched roof, such that the charge may be 400–600 mm. thick. The charge is introduced slowly (taking about 2 hr.), and the coking period is 12–16 hr. The feature of the process is that coals unsuitable for normal coke-making can be used; at Corby a non-caking coal with 35 per cent. of volatile matter is used; the temperature of coking is 1,300° C.

The Upgrading of Small Coal. K. C. Appleyard. (Iron and Coal Trades Review, 1935, vol. 130, Feb. 15, pp. 296–297). The author discusses the problem of the disposal of small coal at collieries, and points out the advantages of medium-temperature carbonisation as a means of producing an open-grate coke from this material.

The British Coal Distillation Company's Plant at Newbold, Leicestershire. (Engineering, 1935, vol. 139, Mar. 15, pp. 293–294). The arrangement of this plant, where coal is carbonised in a modified "L & N" retort, is shown, and the results of operating tests are reported.

Extension to the Works of Doncaster Coalite Limited. (Iron and Coal Trades Review, 1934, vol. 129, Dec. 28, p. 1017). The extension consists of 72 retorts, whilst the by-product plant has been duplicated. A cellular system of construction is adopted, and the retorts are heated by radiation. After condensation in the hydraulic main the gas is treated in an electrostatic precipitator, passes through a bubbler for ammonia recovery and so to the exhaust scrubbers, &c., and gas-holder. A description of the working of the process is given.

Coal Tar. J. Giron. (Arts et Métiers, 1934, vol. 87, Nov., pp. 257–259 ; Dec., pp. 266–275 ; 1935, vol. 88, Jan., pp. 12–14 ; Feb., pp. 34–37 ; Mar., pp. 55–57). The author discusses the formation, the collection, the constituents, and the treatment of tar from the gasworks point of view.

Coke in the Foundry Cupola. W. Hollinderbäumer. (Giesserei, 1935, vol. 22, Feb. 15, pp. 73–75). The author presents some of the results obtained in an investigation carried out by a joint commission of the Verein deutscher Eisengiessereien and the Rheinisch-Westfälischer Kohlensyndikat to determine the influence of the characteristics of the coke used on the operation of the foundry cupola. The physical and chemical properties of the cokes used were examined and observations were made of the dimensions and working of the cupola. The following are the conclusions arrived at : (1) The melting process in the cupola requires tough, strong coke ; (2) the toughness of coke is considerably affected by the coking period ; (3) contrary to previous opinion, the lump size of good foundry coke is of subordinate importance in the melting process ; (4) the type and construction of the cupola have a great influence on the results obtained ; (5) no reliable conclusions as to the quality of a foundry coke can be drawn from its appearance ; (6) frequently the cause of momentary bad results with a given kind of coke in a given cupola lies in the condition of the repair material used in the cupola.

Properties of Foundry Coke. W. E. Mordecai. (Coke-Oven Managers' Association, Dec. 20, 1934 : Gas World, 1935, vol. 102, Feb. 2, Coking Section, pp. 7–8).

Reactivities to Carbon Dioxide of Cokes and other Forms of Carbon at High Temperatures. T. H. Blakeley and J. W. Cobb. (Institution of Gas Engineers, 1935, Communication No. 104).

GASEOUS FUEL.

Modern Gas Producers in the Metal Trades. (Fuel Economist, 1935, vol. 10, Apr., pp. 821–823 ; May, pp. 863–867). A survey of modern gas producer practice, with special reference to the constructional and operating features of some modern producers.

Breeze Burning in Producers. (Fuel Economist, 1934, vol. 10, Dec., pp. 620–623). A discussion of gas-producer practice using breeze and small coke.

Gas Producer Capacity is Increased by Blowers. A. E. Seelig. (Steel, 1934, vol. 95, Nov. 19, pp. 50–51). A brief discussion of the advantages of the turbine blower for the independent control of steam and air admission in gas producers. The blower is a

centrifugal fan driven by a steam turbine, usually mounted either on the charging floor of the producer house, or on the producer floor itself. The air supply is controlled by varying the speed of the turbine by means of a throttle placed in the steam line. Control of the steam admission is entirely independent of the air delivery.

Advantages of the Complete Purification of Producer Gas. J. Morange. (Génie Civil, 1934, vol. 105, Dec. 15, pp. 555–558). The author discusses the advantages of removing all the tar and nearly all the water vapour contained in crude producer-gas before it is used for firing metallurgical and other furnaces. The dust must be removed from the gas on leaving the producer, and this should be done at high temperature to prevent the dust from carrying down the condensable fractions of the heavy tars (pitch). For condensing simultaneously the tar and steam, spraying is the only economic industrial process, and the gas should be cooled below 45° C. ; when so cooled, the gas contains only small quantities of light hydrocarbons. At first glance, it might appear preferable to leave the tar in the gas on account of its heating value, but in practice this is not so, because the rate of combustion of tar is too slow and the amount of air introduced into metallurgical furnaces is insufficient to burn both the tar and the gas. The author presents a heat balance from an actual case ; from this there appears to be a loss of heat due to the cooling spraying of the gas, but he shows that this has not the practical importance that might be thought ; the gas is generally preheated for use, and recuperation is more satisfactory with cold than with hot gas, and can be carried to a higher temperature. The author also gives figures to demonstrate the benefit of drying the gas, and concludes with a brief consideration of the cost of installing and operating the necessary purification plant.

Electrical Gas Cleaning. G. Kroupa. (Montanistische Rundschau, 1934, vol. 26, Dec. 16). Details are given of the W.W.D. electro-detarrer and the Whessoe electro-dedusting plant (*see* Journ. I. and S.I., 1933, No. II. p. 525).

Investigations on Electro-Filters. The Influence of the Suspended and the Precipitated Dust on the [Electrical] Characteristics of Electro-Filters. G. Mierdel. (Wissenschaftlichen Veröffentlichungen des Siemens-Konzerns, 1934, vol. 13, p. 94 : Zeitschrift des Vereines deutscher Ingenieure, 1934, vol. 78, Nov. 17, p. 1346).

"Gyrepur" Appliance for the Dry Dedusting of Gases. (Génie Civil, 1934, vol. 105, Nov. 24, p. 486). A very short description and sketch of this dry gas dedusting appliance is given. The dusty gas passes through a vertical rotating cylinder, of which the wall is a grid. Vanes within the cylinder impart a suitable movement to the gas, such that the dust is expelled through the grid while the gas passes out at the top end of the cylinder. The

dust collects in a surrounding casing and falls to the bottom, whence it is removed through a "lock chamber."

Dry De-dusting of Blast-Furnace Gas. A. I. Verhoturov. (Iron Age, 1935, vol. 135, Apr. 25, pp. 19–21, 86, 88). A description is given of a centrifugal de-dusting appliance in use in Russia. The dust-laden gas passes through an annular chamber between a barrel fitted with vanes, and the casing of the cleaner. The dust particles are driven through grids in the outer casing and fall to the bottom; the cleaned gas passes out at the top end. The cylinder with the vanes is rotated by a 50-H.P. motor at 290 r.p.m., when very fine cleaning is obtained. The method is said to be clean and cheap.

Lodge-Cottrell Blast-Furnace Gas-Cleaning Plant at the Pretoria Steel Works. (Iron and Coal Trades Review, 1934, vol. 129, Nov. 30, p. 849). Brief particulars are given of the Lodge-Cottrell gas-cleaning equipment at these works, which is operated on the 2-stage principle.

The Application of Town Gas to Industrial Heating Problems. G. H. F. Windiate and E. B. Craddock. (Manchester and District Association of Gas Engineers, Oct. 26, 1934: Gas World, 1934, vol. 101, Nov. 17, Industrial Gas Supplement, pp. 7–10).

Spherical High-Pressure Gas-Holder. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, May 11, pp. 590–591). Brief particulars are given of a spherical high-pressure gas-holder, 15·7 m. in diam., with a cubic content of 2,000 cu. m., and designed for a pressure of 5 atm. It will be used in conjunction with a long-distance gas supply service.

Storage and Transport of Compressed Gases. Autofrettaged Containers on the System of G. Ferrand. G. Benoist. (Génie Civil, 1935, vol. 106, Apr. 20, pp. 387–389). After referring to the use of autofrettaged tubes for the penstocks of hydraulic power stations, the author describes gas containers constructed on the same principle, made by Les Etablissements Bouchayer et Viallet, of Grenoble. They consist of a welded cylindrical body, encircled by weldless heat-treated hoops, the ends being closed by hemispherical stampings; special high-tensile, high elastic limit steel is used. Containers up to 1 m. in diam. for pressures of 200 kg. per sq. cm. and up to 700 mm. for pressures of 250 kg. are made; they are very light.

Long-Distance Gas in the Saar. F. Vieler. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Feb. 2, pp. 137–138). The author touches briefly on some of the problems confronting the coal, coke and iron industries of the Saar, now that the country has been returned to Germany, and then outlines the activities of the Ferngasgesellschaft Saar (the Saar Long-Distance Gas Co.).

LIQUID FUEL.

The Hydrogenation of Bituminous Coal. M. Pier. (Chemistry and Industry, 1935, vol. 54, Mar. 29, pp. 284–288: Iron and Coal Trades Review, 1935, vol. 130, Mar. 22, pp. 485–486; Mar. 29, pp. 543–545). A description is given of large-scale experiments on the hydrogenation of bituminous coal carried out at the plant of the I.G. Farbenindustrie at Ludwigshafen.

Hydrogenation of Low Temperature Tar and Tar Products. F. S. Sinnatt. (Midland Association of Gas Engineers and Managers, Nov. 1, 1934: Gas World, 1934, vol. 101, Nov. 24, pp. 556–559).

High-Pressure Plant for Experimental Hydrogenation Processes. A. T. Barber and A. H. Taylor. (Institution of Mechanical Engineers: Engineer, 1935, vol. 158, Nov. 23, pp. 523–524; Nov. 30, pp. 550–552).

The Wyndham Liquid-Coal Process. (Engineering, 1935, vol. 139, Feb. 1, p. 117). Illustrated particulars are given of the Wyndham machine for the production of "liquid coal," a mixture of coal and oil.

Liquid Fuel and the Heat Treatment of Steel. D. A. Whitehead. (Steel Treatment Society, Australia, Nov., 1934: Heat Treating and Forging, 1935, vol. 21, Feb., pp. 89–93, 97). The author describes the characteristics and combustion of oil fuel and touches upon its applications in the forging and heat treatment of steel.

Propane and Butane as Industrial Fuels. E. A. Jamison and W. H. Bateman. (Iron and Steel Engineer, 1935, vol. 12, Apr., pp. 209–213). The authors discuss the characteristics of propane and butane and their utilisation for industrial purposes. One application of interest to the steel industry is the use of propane for the cutting of steel, and particulars are given of the results of tests with this fuel. The advantages of these gases over fuel oil are enumerated.

PRODUCTION OF IRON.

PIG IRON.

Indiana Harbour Plant of the Youngstown Sheet and Tube Company. C. Longenecker. (Blast Furnace and Steel Plant, 1935, vol. 23, Jan., pp. 46–56). A complete illustrated description is given of the layout and equipment of this plant, which comprises ore docks, coke-ovens, blast-furnaces, open-hearth department, Bessemer converters and rolling-mills.

The Development of the Modern Blast-Furnace. A. G. McKee. (Iron and Steel Engineer, 1935, vol. 12, Jan., pp. 1–15). The author presents a brief history of the American iron industry during the last half-century, and traces the trend in furnace capacities and the recent tendency toward larger hearths. Furnace lines, linings and refractory materials, ore storage and stove construction are discussed. Particular attention is given to the subject of hot-blast stoves, and the suggestion is made that stoves of the future will have checkers of smaller size and thinner walls, and will be of a uniform size and shape from the top of the stove to the bottom.

The Development of Blast-Furnace Lines in Russia. M. A. Pavloff. (Metallurg, 1932, No. 7, pp. 68–87 : Hutnik, 1934, vol. 6, pp. 18–20 : Stahl und Eisen, 1935, vol. 55, Feb. 21, p. 216). The author discusses the development of blast-furnace lines in Russia. The hearth diameter has been increased to 8·3 m. with a bosh angle of 84°, the daily output having thus been raised to 1,175 tons. The height of the boshes has been reduced to 3 m. and even 2·65 m. The attempt has been made to increase the bosh angle to 86° ; the author thinks, indeed, that the angle might be increased to 90°, provided that the conical shaft is retained. In general, these changes of profile resulted in decreased disturbances due to accretions and scaffolding. The lines of eleven furnaces are tabulated, and the author discusses them critically.

Blast-Furnace Capacities in Russia. M. A. Pavloff. (Hutnik : Iron and Coal Trades Review, 1935, vol. 130, Apr. 5, p. 592). The dimensions of blast-furnaces in operation in Russia are tabulated.

Clay Gun Stops Iron Notch Under Full Blast-Pressure. (Steel, 1934, vol. 95, Dec. 24, pp. 39–40). An outline is given of the various improvements effected in the design and construction of

the Brosius clay gun. To meet the modern trend of electrifying all equipment, the two-motor automatic gun was developed in 1933. This gun has a single clay barrel with a capacity of 9 cu. ft. A distinctive feature is the elimination of the clamping mechanism. The gun is pulled into the hole and held in position by a rope attached to the furnace front and wound on a worm gear operated by a 10 H.P. motor, mounted inside the boom ; the splasher plate is automatically raised as the gun swings in. The iron notch is stopped completely—under full blast pressure—in from 8 to 12 sec., depending on the amount of clay required. The entire equipment is controlled from any convenient point in the casting house. The gun proper is driven either by a straight mechanical gear drive or by a self-contained motor-driven hydraulic oil gear unit, this unit and its driving gear being mounted on the gun.

Increasing the Heating Surface of an Existing Hot-Blast Stove by Means of Inserts in the Checkerwork. K. Skroch. (Hutnik, 1934, vol. 6, pp. 61–68 : Stahl und Eisen, 1935, vol. 55, Feb. 28, p. 240). The author describes his experience in increasing the heating surface of a hot-blast stove by the use of inserts in the checkerwork. For the same hot-blast temperature, the waste gas temperature was reduced by 120° and the gas consumption was also considerably lowered. On the other hand, the fall of temperature while " on air " increased ; without the checkerwork it amounted to 105°, but with it the drop increased to 160°.

New Checker Brick Increases Hot Blast Stove Efficiency. (Steel, 1934, vol. 95, Dec. 10, pp. 49, 51). **Performance of Open-Joint Checkers in Blast-Furnace Hot Stove.** M. K. Mellott. (Iron Age, 1934, vol. 134, Dec. 20, pp. 26–27). **Checker Increases Stove Efficiency.** A. Bowland. (Blast-Furnace and Steel Plant, 1934, vol. 22, Dec., pp. 695–697). The construction of a hot-blast stove at the plant of a large steel producer in the U.S.A. is described, particular attention being given to the open-joint checker brick employed. Each checker interlocks with an adjoining brick at all four corners. The types of checker used depend on the positions occupied in the stove. It is claimed that the checkerwork permits the unimpeded flow of gas, provides maximum heating surface at minimum cost, and improves structural stability. Photographs of the brickwork and a performance chart comparing stoves with plain and special checkerwork are given.

The Use of Zoned Checkers in Hot-Blast Stoves Operating with Uncleaned or Partially Cleaned Gas. (Iron and Coal Trades Review, 1934, vol. 129, Nov. 23, pp. 803–804). Particulars are given of the " Duoflex " checker arrangement built into a hot-blast stove at a British plant in June, 1933. The gas used is

only partially cleaned and may contain from 0·5 to 1·5 grm. of dust per cubic metre of gas. The top zone of the checkers is formed of straight-walled vertical passages, the middle zone is formed of vertical passages in each of which two opposite walls are continuously curved and the other two are straight, and the bottom zone is formed of vertical passages in each of which all four walls are continuously curved. The introduction of the checker system enabled one stove less to be used in the cycle, and the increased efficiency allowed for a longer period "on blast"; as a result the average blast temperature was substantially raised and increased outputs were obtained from the furnace. The one drawback of the checker system was the dust accumulation found to have taken place at the junction of the top and middle zones. A modified design of checker has been introduced to overcome the difficulty of choking. The new design is illustrated and its advantages are pointed out.

Study of the Draft in a Cowper-Stove Chimney System. A. Peters. (Revue Technique Luxembourgeoise, 1934, vol. 26, Nov.-Dec., pp. 129–138). The author presents a study of the variations of pressure, the pressure losses and the draft resulting from the combustion of the gas in the combustion shaft of a hot-blast stove, during the passage of the waste gases through the stove, along the flue and in the chimney. The author first records graphically the pressures measured at various points in the system, and discusses the results obtained. He next gives a succinct review of the theory of the flow of fluids, and then applies this theory to the flow of waste gases (*a*) in the combustion shaft, (*b*) in the checkerwork, (*c*) in the flue, and (*d*) in the chimney. Finally, he deals with the calculation of the pressure regime in a hot-blast stove consuming a given amount of gas.

Centralised Remote Control in a Modern Blast-Furnace Plant in Germany. R. W. P. Leonhardt. (Chaleur et Industrie, 1934, vol. 15, Dec., pp. 358–364). *See* Journ. I. and S.I., 1934, No. I. p. 455.

British Blast-Furnace and Open-Hearth Practice, 1910-1935. E. C. Evans. (Iron and Coal Trades Review, 1935, vol. 130, May 3, pp. 743–745). The author reviews developments in the manufacture of pig iron and open-hearth steel in Great Britain. Statistics of production are shown, and a table is included which indicates that the fuel consumption in blast-furnaces has decreased during the past twenty-five years by 12½ per cent.

Modern Tendencies in Blast-Furnace Practice. L. P. Sidney. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 161–168). The author first comments on the research work which has been and is being carried out, and proceeds to review the present state of blast-furnace practice in Great Britain compared with that in

other countries. He points out that outputs tend to increase, and suggests some of the factors which govern output (such as the size of the furnace, methods of charging, nature of the fuels, ores and fluxes and rate of drive). The author then briefly describes certain items of equipment installed at various works during 1934.

Presidential Address. A. McCance. (Journal of the West of Scotland Iron and Steel Institute, 1934–35, vol. 42, Part I., Oct., pp. 3–10). A review of the trend in developments in blast-furnace practice.

A Chemical Engineer Views the Steel Industry. C. F. Ramseyer. (American Institute of Mining and Metallurgical Engineers, 1934, Technical Publication No. 582 : Iron Age, 1934, vol. 134, Nov. 22, pp. 26–30). The author proposes a number of revolutionary changes in the methods of producing iron and steel. The use of oxygen instead of air in the blast-furnace, and the replacement of the open-hearth furnace by a shaft furnace in which molten pig iron and scrap, each brought to it independently, would be intimately mixed with a counter-current of oxidising slag, are suggested.

The Physico-Chemical Principles of the Burdening of Iron Ores (Part I.). J. Klärding. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Jan., pp. 277–280). The author has carried out experiments to determine the influence of the flux and foreign oxides on the reduction of the iron oxide in iron ores. Mixtures of iron oxide, lime and silica in various proportions were prepared by incorporating the corresponding nitrate solutions with silica gel and drying the mass ; the finely powdered mixture was then heated to red heat or melted. Reduction tests under carbon monoxide gas were carried out and the course of the reactions was observed. The most suitable ratio of lime to silica in the burden was found to be $2CaO : 1SiO_2$. In calcium orthosilicate the lime and silica are so firmly combined that the reduction of the iron oxide to iron can proceed without interference ; this was proved in tests at 800°, 900° and 1,000°. The decomposition curves enable conclusions to be drawn regarding the lime/silica and lime/silica/ferrous-oxide equilibrium diagrams.

The Physico-Chemical Principles of the Burdening of Iron Ores. (Part II.). J. Klärding. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Feb., pp. 325–328). Reduction experiments on pure mixtures of iron oxide, lime and alumina showed that the most favourable burden of these three materials is one in which the lime and alumina are present in a molar ratio of 1 : 1. As lime reduces the influence of alumina on the reduction of iron oxide, alumina can, in the usual sense, be regarded as acid. In a homogeneous mixture, dicalcium ferrite is not stable in the presence of alumina, at least over a very wide range of mixture. Until

the lime is present in very large excess, spinel occurs as a stable phase in the presence of low oxygen contents in the mass.

Observations and Theory on Slack Wind Blast-Furnace Operation. F. M. Rich. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 617 : Iron Age, 1935, vol. 135, Feb. 28, pp. 30–32, 38 : Steel, 1935, vol. 96, Mar. 4, pp. 69–70, 73 ; Mar., 11, p. 52). In order to meet the conditions set up by the economic depression, many American blast-furnace superintendents have been obliged to adopt slow driving or decreased blast for the operation of their furnaces. The author discusses the fundamentals of slow driving and points out its advantages. He concludes that practically all American blast-furnaces were overblown prior to the depression.

The Injection of Flue Dust into Blast-Furnaces by the Heskamp Process. O. Wehrheim. (Stahl und Eisen, 1934, vol. 54, Dec. 6, pp. 1253–1256). The Heskamp process of flue-dust injection into blast-furnaces was described by R. Milden in Stahl und Eisen, 1931, vol. 51, p. 1133. The present author gives details of its application to two blast-furnaces belonging to the Koninklijke Nederlandsche Hoogovens en Staalfabricken at Ymuiden (Holland), and of the influence of its introduction on the operation of the furnaces. It is shown that this process is simple, cheap and safe ; the dust is transferred from the dust collector through a closed circuit back to the blast-furnace as fully equivalent to ore. The withdrawal of the dust from the collector, which is necessary for briquetting or sintering, and all the attendant inconveniences are avoided. The cost of injecting the dust is lower (never higher) than that of transporting the dust to the preparation plant, storing it and carrying it back to the ore bunker and furnace top, where, further, a portion of the briquetted or sintered product is converted into dust again. If the process is carried out with due care, no disturbance of the operation of the furnace nor off-grade iron and slag need be feared. The injection nozzles should be placed as far above the tuyere level as possible, so that the injected dust may have the maximum distance to travel down to the tuyere level, but in a zone where the dust may be picked up by already softened particles of the burden. The process also allows of the extensive and rapid regulation of the furnace operation, simply by increasing or decreasing the amount of dust injected. The experiments described by the author show that the process is equally well applicable to furnaces exclusively making high-quality special irons.

Operating Results of a Minette Blast-Furnace without and with Scrap Additions. M. Steffes. (Stahl und Eisen, 1935, vol. 55, Jan. 3, pp. 17–20). After a brief account of the operation of a blast-furnace working on minette ore only, the author describes the influence of increasing additions of scrap to the burden, as

revealed by large-scale tests. With a blast temperature of 800°, the coke carbon consumption per ton of pig iron produced from scrap averaged out to 288·6 kg. The volume of throat gas and of blast required decreased very much as the scrap addition was increased. The composition of the throat gas and its heating value did not vary much ; on the other hand, a slight increase in the temperature of the throat gas was observed. A critical comparison with other similar experiments was not possible, as the operating conditions differed too widely.

Further Determinations of the External Heat Loss of Blast-Furnaces. D. F. Marshall. (Iron and Steel Institute, May, 1935, this Journal, p. 59).

Experiments on the Complete Reduction of Manganese Oxide in Molten Iron. E. Diepschlag. (Metallwirtschaft, 1935, vol. 14, Feb. 8, pp. 107–110). The author first points out that only about 80 per cent., at most, of the manganese in the burden of a blast-furnace finds its way into the pig iron ; the manganese oxides are reduced first to MnO, and as this requires a very high temperature for its reduction it reacts first with silica to form silicates which initially are not reduced. Lower in the stack reaction with lime takes place and the MnO set free is reduced, but these reactions are dependent on the lime concentration and the temperature, and under present usual operating conditions these factors cannot be improved upon. The author then discusses the reduction of manganese oxide by iron, and shows that the reaction can be carried further by the provision of a reducing agent to react with the FeO produced. He melted an iron-carbon alloy (carbon, 4·57 per cent.) in a graphite crucible in a carbon-ring electric furnace at 1,650° C., and added pellets of compressed manganese oxide. Though the results as tabulated show irregularities, nevertheless, it appeared that complete reduction took place ; no slag formed on the surface of the melt. The loss of manganese was attributed to spraying during the evolution of CO from the melt and to vaporisation of the metal. To determine the influence of silica, further tests were carried out in exactly the same way, while increasing quantities of silica were added. The silica was reduced as well, and no slag formed on the surface of the melt. The high carbon content of the metal was essential for the complete reduction of the manganese oxide ; repetition of the tests in a sintered-corundum crucible open to the air or with low-carbon iron in an alumina boat under hydrogen failed, as slag formed on the melt.

An Approximate Value for the Heat of Formation of an Iron Phosphide (Fe_2P). W. A. Roth, A. Meichsner, and H. Richter. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Dec., pp. 239–241). The heat of formation of crystalline $FePO_4$ from Fe_2O_3 and P_2O_5 was found, by solution in hydrochloric acid, to be + 21·6 k.-cal.

The heat of formation from the elements amounts to + 303·9 k.-cal. when the calculation is based on the use of red phosphorus. From the oxidation of Fe_2P and $2Fe_\alpha + P_{red}$ it follows that the most probable value for the heat of formation of Fe_2P is +41 k.-cal. with a possible error of about 10 per cent. All values are referred to about 20° C. and constant pressure. Attempts to compel iron and phosphorus to combine completely by strong electric heating in an evacuated bomb failed. The heats of formation of the other iron-phosphorus compounds were calculated: FeP, 28·5 k.-cal.; FeP_2, 37·5 k.-cal. (possible error, 10 per cent.). Their heats of decomposition must be taken into account when working out the thermal reactions in the basic Bessemer converter.

The Volatilisation of Silicon and Silica by Sulphur and Its Importance in Practice. P. Dolch. (Montanistische Rundschau, 1935, vol. 27, Jan. 1, pp. 3–4). The author first reviews a number of early papers which had to do with the reactions of silicon or silica with sulphur in the blast-furnace and their effects. Silicon sulphide is formed when carbon disulphide vapour is passed over a mixture of soot and silica at a white heat; the SiS_2 volatilises, and condenses in the cooler parts of the apparatus, and on heating in the air decomposes into silica and sulphur dioxide. Ledebur stated (1878) that the high silica contents of blast-furnace gas and of the smoke from the fore-hearth, were probably due to the volatilisation of silicon sulphide; further, the smoke, consisting largely of silica, and the often noticeable smell of sulphur dioxide arising when manganiferous spiegeleisen was tapped, pointed to the same cause. The author then touches on several publications dealing with desulphurisation in the electric furnace, and suggests that the high degree of sulphur removal obtained is due to the formation of volatile silicon sulphide.

The Blast-Furnace as a Chemical Plant. C. O. Bannister. (Chemistry and Industry, 1934, vol. 53, Nov. 23, pp. 991–996). The author reviews developments in the recovery of by-products from the blast-furnace. In the past the most important by-products have been tar and ammonia, which were recovered from coal-fired blast-furnaces, especially in Scotland. The behaviour of cyanides in the furnace, the recovery of potash and the proposals put forward in Russia to use the blast-furnace as a producer of a gas-mixture suitable for the manufacture of synthetic ammonia are dealt with, also the recovery of zinc from zinc-bearing ores, the recovery of iodine from the flue dust at Witkowitz, and the use of the blast-furnace for the production of phosphoric acid.

The Behaviour of the Sulphides in Blast-Furnace Slag in Cement, Mortar and Concrete. H. Burchartz and E. Deiss. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Nov., pp. 181–186). In order

to investigate the influence of the sulphur in blast-furnace slag on the properties of concrete in which it was an ingredient, small test blocks were prepared and were tested by storing them (*a*) in moist air, (*b*) half immersed in distilled water, and (*c*) immersed in distilled water through which air bubbled continuously. The raw materials used were a Portland cement, a clay cement, two blast-furnace slags, rich and poor in sulphide, respectively, Berlin wall sand and distilled water. Similar tests were first carried out in which the slag was replaced by standard sand (sulphur-free) to check the behaviour of any sulphate present in the cement. After storage for two weeks, four weeks, three months and one year, the total sulphur and SO_3 were estimated in the blocks, and the sulphide was calculated by difference ; the total sulphate in the water used in test series (*b*) and (*c*) was also determined after the three shorter periods. The results showed that in the presence of water the blast-furnace slag imparted practically no sulphide to the concrete in which it was incorporated. The oxidation of the sulphide was very slight and of no practical importance. Depreciation of mortars or concrete containing slag due to the oxidation of sulphide to sulphate is, therefore, not to be expected, and there is no basis for scruples in the unrestricted use of blast-furnace slag as an ingredient in mortars and concrete for underwater structures. These results are the more noteworthy because the test conditions were particularly favourable for the oxidation of the slag sulphide ; the mortars were very lean and therefore porous so that air and moisture had easy access, and the slag additions used were fairly fine-grained.

Use of Blast-Furnace Slag as Fertiliser in Holland. J. Hudig. (Mededelingen van de Landbouwhoogeschool te Wageningen, 1933 : Stahl und Eisen, 1935, vol. 55, Jan. 24, pp. 91–92). The author describes tests carried out in an investigation of the manurial properties of a fertiliser known as "Silikakalk," produced from blast-furnace slag by the Koninklijke Nederlandsche Hoogovens en Staalfabricken in Ymuiden.

DIRECT PROCESSES.

The Direct Production of Iron by the Krupp Process. (Génie Civil, 1935, vol. 106, Jan. 26, pp. 84–87). After a brief review of earlier processes for the direct production of iron, the Krupp process and its product are described, and the industrial applications of the direct iron are discussed.

IRON INDUSTRIES.

Raw Material Problems of the German Metal Industry. E. Söhnchen. (Giesserei, 1935, vol. 22, May 24, pp. 255–259). One

of the aims of the reorganisation of the German metal industry is to supply internal metal requirements so far as possible from internal sources; various ways of attaining this end have been suggested, and these the author discusses. In the first part of the article he reviews the principal ore deposits in Germany, and in the second he deals with economic aspects.

The Russian Iron Industry and Its Economic Development. H. Hartig. (Stahl und Eisen, 1935, vol. 55, Mar. 14, pp. 304–310). The author discusses the subject under the following headings: The natural basis (a brief tabulation of the principal Russian ore deposits is given); the economic development; pig iron and steel production; and special features of the post-war development.

Developments in Soviet Russia. (Metallurgia, 1935, vol. 11, Feb., pp. 105–106). Data are provided of the industrial advance of Russia, including ferrous and non-ferrous metal production.

HISTORICAL.

Notes on a Pre-Historic Iron Bloomerie Found at Point of Knap, Loch Sween. D. A. MacCallum. (Journal of the West of Scotland Iron and Steel Institute, 1934, vol. 42, Nov., pp. 29–32). The remains of an old "bloomerie" found at Knap are mentioned, and a number of references made to the ironworks of antiquity. The method of working is discussed and the historical development of the iron-making industry in Scotland is sketched.

Is Central Europe the Cradle of Iron Technology? H. C. Richardson. (American Journal of Archæology, 1934, vol. 38, pp. 555–583: Stahl und Eisen, 1935, vol. 55, Mar. 21, pp. 341). The author discusses the question of the origin of the production of iron. He describes a new example of the very early use of terrestrial iron, namely, a bronze dagger with an iron blade found at Tell-Asmar in Irak, dating from about 2800 B.C. The author agrees with the views of archæologists that up till the actual "Iron Age" iron was used only sporadically. He believes that this iron was not produced in the East, as ore deposits are of rare occurrence there, but that the early iron was transported there from Europe. Actually, nowhere in the East, is iron so widely distributed as in Italy, Austria, the Balkans and the Alps. To account for the trade in iron, the author points to the lively commerce between Central Europe and the East which had already developed by the third century B.C.

The History of the Bochumer Verein für Bergbau und Gussstahlfabrikation. (Stahl und Eisen, 1935, vol. 55, Jan. 31, pp. 110–114).

FOUNDRY PRACTICE.

GENERAL FOUNDRY PRACTICE.

Progress and Development in Cast Iron during 1934. J. E. Hurst. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 169–170). Reference is made to the development of foundry practice as a science, and to the results of recent investigations, especially those concerned with alloy cast irons.

Foundry Developments in 1934. A. L. Norbury. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 171–174). During 1934 many advances have been made, notably with regard to the closer grading of pig irons, the production of refined irons, the use of alloy cast irons, and the control of graphite. The balanced-blast cupola has gained new adherents, whilst rotary furnaces have increased in numbers.

Cupolas Supply Molten Iron Continuously. P. Dwyer. (Foundry, 1934, vol. 62, Nov., pp. 28–30, 80). An account is given of cupola practice at the grey iron foundry of the Chevrolet Co., Saginaw, Michigan. Two batteries of six cupolas each are installed. Six cupolas are in blast at one time. Approximately 2,000 tons of iron are melted every 24 hr. day.

Political-Economic Considerations on Obsolete Cupola Operation. A. Löbner. (Giesserei, 1935, vol. 22, Mar. 15, pp. 129–133). The author discusses the uneconomic operation of obsolete cupolas in the light of modern melting technique and gives practical examples of possible remedial measures. He discusses the thermo-technological importance of the various reactions concerned in the melting process and gives figures to show the considerable waste of fuel which may occur under certain circumstances in badly-managed cupola operation.

Cupola Practice and Carbon Control. W. H. Bamford. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, Mar. 7, pp. 169–172, 174). An account is given of some experiences with semi-steel for the production of monobloc castings and cylinder heads. The procedure adopted is indicated, and the influence of carbon (among other factors) is referred to.

Carbon Loss and Pick-Up in the Cupola. H. H. Langebeck. (Metals and Alloys, 1935, vol. 6, Feb., pp. 31–34). This article is a correlated summary of the results of numerous investigators on the subject of carbon loss and pick-up. The effects of impurities in the charge, the quality of the coke, the volume of blast, and the size of the cupola are considered.

The Treatment of Cast Iron with Sodium Carbonate. (Metallurgia, 1934, vol. 11, Nov., pp. 9–11). The employment of sodium carbonate as a refining flux is now standard foundry practice, and special equipment has been designed to improve the efficiency of the process. One such item is a fore-hearth or receiver, adjacent to the cupola, and into which the iron is tapped by a short launder. A trap is provided in the latter in order to effect slag removal; this prevents contamination of the iron by cupola slag. The refined iron is tapped from the bottom of the receiver, and the sodium carbonate slag flows from a spout higher up. If the provision of a receiver is not desirable, the treatment may be carried out in a tea-pot type of ladle, in which the spout draws off clean metal from the bottom, a partition being used to keep back the slag. The latter may be thickened with ground limestone in order to facilitate its removal.

Rotary Melting Furnace Practice. S. E. Dawson. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, Feb. 28, pp. 155–156). A description is given of a rotary furnace for the melting of cast iron. The furnace is fired by pulverised coal, forced draught being applied by a Roots blower; the air is preheated by a recuperator. The method is said to be very flexible and well suited to the production of finely graphitic cast iron.

Iron Superheated in Open-Hearth. F. Brocke. (Foundry, 1935, vol. 63, Feb., pp. 32, 64). Particulars are given of a process for the superheating of cast iron in an open-hearth furnace of the Schury type. The furnace is oil-fired, the consumption of fuel being approximately 4 per cent. of the charge.

The Electric Melting of Cast Iron. A. G. Robiette. (Metallurgia, 1935, vol. 11, Feb., pp. 101–104). The application of superheat to grey cast iron is well known. With low-carbon grey iron this is somewhat difficult to carry out in the cupola. However, low-carbon material may be successfully produced from light scrap in the electric furnace. Moreover, there is less sulphur and phosphorus pick-up, and the melting losses are smaller. The duplex process may be advantageously worked, since cheaper raw material can be used in the cupola, the final superheating and refining being done in the electric furnace. In the production of malleable iron, the electric furnace enables a considerable degree of superheat to be attained, so reducing the time required for malleablising.

High-Duty Cast Iron in the Foundry. G. Hall. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, Jan. 17, pp. 57–58). Some considerations relating to the production of alloy and refined cast irons are dealt with.

Use of Cast Iron Scrap in Cupola Expedited By Addition of High Silicon Iron. H. A. Dierker. (Iron Age, 1935, vol. 135,

May 16, pp. 23–25). A series of melts was run in a small cupola, using various proportions of scrap in the charges. Bars were cast and tested transversely. Ferro-silicon was used to improve the grade of the iron. The tests showed that with careful selection of the scrap, and with proper cupola practice, it should be possible to produce good-quality iron.

Rotary Type Mill Cleaning Machines. L. M. Waite. (Iron Age, 1935, vol. 135, Mar. 7, pp. 24–25, 80). Illustrated particulars are given of the constructional arrangement of rotary-drum machines for the tumbling and cleaning of metal parts.

Abrasive Cleaning Without Compressed Air. (Iron and Steel Industry, 1935, vol. 8, Mar., p. 232). In a device known as the wheelabrator, abrasive material is thrown on to the work by centrifugal force, thus dispensing with compressed air. It is stated to be flexible and efficient.

Foundry Costing. J. Roxburgh. (Institute of British Foundrymen : Foundry Trade Journal, 1935, vol. 52, Feb. 28, pp. 159–162, 164). The author discusses the factors which enter into foundry costing, with particular reference to metal costs and overhead charges.

The Distribution of Work and its Consequences in the Foundry. G. Schmidt. (Giesserei, 1935, vol. 22, Jan. 4, pp. 1–3).

MOULDS AND CORES.

Patternmaking. A. Marshall. (Institute of British Foundrymen : Foundry Trade Journal, 1935, vol. 52, May 23, pp. 343–344, 350). A number of patterns are described illustrating some of the matters which require special attention.

Patternmaking Economics. H. Stead. (Institute of British Foundrymen : Foundry Trade Journal, 1935, vol. 52, May 16, pp. 333–334). The author discusses some of the factors which bear upon the economics of patternmaking.

The Steaming and Drying of Wood in the Patternmaker's Shop. O. T. Koritnig. (Giesserei, 1935, vol. 22, May 10, pp. 222–225). The author stresses the need for great care in the drying of wood for patternmaking purposes ; this must be carried out on correct thermo-technological lines, as otherwise the plant will work uneconomically and also the wood will not be able to fulfil the demands made on it.

The Possibility of Using Old Patterns. R. Löwer. (Giesserei, 1935, vol. 22, May 10, pp. 225–229). The author gives a number of examples taken from practice, showing how, frequently, it is possible to use old patterns by making suitable alterations, so economising both material and costs.

Use Plaster for Foundry Patterns. (Foundry, 1934, vol. 62, Sept., pp. 12–13, 52–54 ; Oct., pp. 46–48, 104 ; Nov., pp. 34–35, 70 ; 1935, vol. 63, Feb., pp. 30–31, 62 ; Mar., pp. 32–33, 74). A series of articles dealing with the use of plaster as a foundry pattern material.

Prevent Losses with Proper Gates and Risers. P. Dwyer. (Foundry, 1934, vol. 62, Dec., pp. 47, 49–50 ; 1935, vol. 63, Jan., pp. 38–40, 43 ; Feb., pp. 42, 45, 48 ; Mar., pp. 44, 47–48). The author continues his discussion of the various types of gates and risers used in the foundry industry. (*See* Journ. I. and S.I. 1934, No. II. p. 545).

A New Shape for Risers and Feeder Heads. K. Grocholl. (Giesserei, 1935, vol. 22, Jan. 4, pp. 10–11). It often happens that at the positions most suitable for the placing of risers and feeder heads (with a view to avoiding piping in the casting) the section of the casting is insufficient to provide adequate connection to them. The usual procedure is to increase the section at these points ; this surplus metal then has to be removed afterwards. In many cases, however, the author has got over the difficulty by constricting the extreme bottom end of the feeder head to fit the section ; the small quantity of metal in this constriction is kept molten by the mass of hot metal in immediate contact with it in the head, so that the flow of metal as required is not prevented and the shrinkage cavity forms in the head as desired.

Permanent Mould Castings. F. J. Walls. (Transactions of the American Foundrymen's Association, 1934, vol. 42, pp. 407–417). The author discusses the use of permanent moulds and points out the importance of correct mould design. One of the most important problems in the successful production of permanent mould castings is the correct balancing of the pouring and cooling rates. The structure and properties of iron castings produced in permanent moulds are shown, and a short résumé is given of the casting of alloy irons in permanent moulds.

Plain Jolt Machine Overlooked in Jobbing Foundry Practice. J. N. Eastham. (Iron Age, 1935, vol. 135, Mar. 14, pp. 10–13, 75). The author illustrates some examples of moulding practice in order to show the advantages of plain jolt moulding machines for certain classes of work.

Hold Cores to Close Tolerances. P. Dwyer. (Foundry, 1935, vol. 63, Jan., pp. 28–30, 60, 62). The core making department of the Chevrolet Co., Saginaw, Michigan, and the equipment used are described.

The Standardisation of Tolerances for the Insertion of Cores. F. Brobeck. (Giesserei, 1935, vol. 22, Feb. 15, pp. 79–82). The author points out that the latest and best way to provide for the inaccessible play required for the insertion of cores, is in the

pattern. He gives tables of tolerances for the two cases where the surfaces in question are parallel to and slightly inclined to the direction of insertion; the values given correspond to practice and are the outcome of years of experience.

The Production of Loam Cores. E. Feil. (Giesserei, 1935, vol. 22, Mar. 15, pp. 121–129). The author presents the results of an investigation of the influence on the strength and gas permeability of loam cores produced by variations in the mode of drying, the moisture content, the grain-size and by the addition of various substances (quartz sand, coke dust, sawdust, peat litter, horse dung, coal dust). Many foundrymen attach great importance to the separation of the loam core by "dishing" after casting; it may happen that the best loam, from the point of view of gas permeability and strength in the dry state, may not be usable if it does not possess this property of separating from the casting by dishing.

Why Not Green-Sand Cores? F. Whitehouse. (Iron and Steel Industry, 1934, vol. 8, Dec., pp. 95–96, 98). It is pointed out that green-sand cores may be as good as dry-sand cores, whilst they are also cheaper. The distinctive feature is the core-iron used. Green-sand cores permit a great saving in time to be effected. The important factor appears to be the quality of the sand used.

MOULDING SANDS.

The Testing of Moulding and Core Sands. (Giesserei, 1934, vol. 21, Nov. 23, pp. 497–504). Standard methods of testing moulding and core sands worked out by the Deutscher Verband für die Materialprüfungen der Technik in collaboration with other German technical societies are presented, together with explanatory notes.

Use of the Pipette Method in the Fineness Test of Moulding Sand. C. E. Jackson and C. M. Saeger, jun. (Journal of Research of the National Bureau of Standards, 1935, vol. 14, Jan., pp. 59–65). The fineness, or the size distribution, of the constituent particles of a material is an important factor in determining many of the physical characteristics. No great difficulty is encountered in sizing the larger particles by the use of sieves, but for particles finer than 50 microns in diameter other methods must be employed. The pipette method, which is a modified sedimentation method, has been satisfactorily used in the analysis of particle sizes of soils. It is readily adaptable to the determination of the fineness of moulding sand and has been used for this purpose at the National Bureau of Standards. The method is outlined.

Gas Permeability of Moulding Batch for the Steel Foundry. E. Knipp. (Giesserei, 1935, vol. 22, Mar. 29, pp. 145–148). The gas permeability was tested of a number of moulding sands and batches in the pure state and with various additions, after treatment of the surface of the stamped specimens in various ways, and after drying at various temperatures. In general the permeability of the moulding sands increased with the drying, the increase differing from sand to sand. The permeability in the moist condition gives no indication of the same property in the dry state. An addition of 4 per cent. of core oil reduces the permeability, more so than a similar addition of dry binder. Spraying the sand mould with molasses reduces the permeability slightly, but subsequent drying neutralises the effect. The permeability of moulding batch is very dependent on the work of jolting (compression) and on the moisture content. A slight excess of water above that required, or the direct stamping of the material can reduce the permeability to practically zero. Applying a wash to the mould or over-strickling with spent wash also affects the permeability adversely ; the addition of 50 per cent. of silver sand to the wash gives no practical benefit. Firing these moulds at 600° C. improved the permeability. Pricking increased this property very much, but too much polishing or washing decreased this advantage to some extent. An addition of sawdust to the batch imparted a high permeability.

Coaldust in Moulding Sand. A. Rodehüser. (Giesserei, 1935, vol. 22, May 24, pp. 244–248). The author discusses the mechanical and chemical action of an insulating layer of gas between the mould and the metal cast into it, the prevention of the burning-on of sand on to the casting by a reducing atmosphere, and the effect of an incorrect proportion of coal dust in moulding sand on the casting.

Controlling Dry Sand Strength. H. W. Dietert and F. Valtier. (Foundry, 1934, vol. 62, Dec., pp. 24–25, 56). The authors discuss the effect of clay content, moisture content, temperature, and binders on dry sand strength.

Commercial Moulding Sand Control for the Tyneside Founder. F. Hudson. (Institute of British Foundrymen : Foundry Trade Journal, 1935, vol. 52, Apr. 18, pp. 263–265, 269 ; Apr. 25, pp. 281–282). The author considers that green sand, dry sand and loam are fundamentally the same except for moisture and coal dust additions. He is of the opinion that the repeated use of floorsand does not give rise to silting ; on the contrary, the excessive addition of new sand is responsible for silt. Reference is made to the properties of green and dry sands and the problems of permeability and expansion ; loams are also dealt with. The author then goes on to discuss the types of sand obtained from four Tyneside foundries, from a critical standpoint.

Essentials in the Production of Sound Steel Castings. J. S. Bennett. (Foundry Trade Journal, 1935, vol. 52, Apr. 11, pp. 253, 256). The author briefly mentions the characteristics of the various sands and goes on to discuss the methods of feeding.

SPECIAL CASTINGS.

From the Earliest History of Chill-Casting. E. Schüz. (Giesserei, 1935, vol. 22, Jan. 18, pp. 22–26). The author gives an account of the earliest attempts (from 1822 to 1832) to manufacture chilled cast-iron rolls in Germany, and the invention of the tangential gate for the moulds by Erhardt, the Master Moulder at the Königliche Eisengiesserei in Berlin.

The Technique of Chilling. J. Roxburgh. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, Apr. 11, pp. 249–251). The factors which tend to confer chilling properties in an iron are considered. They are: Low carbon, high sulphur, low silicon, high manganese and high chromium contents. The type of chill produced by each of these is described, and the depths of chill generally required are given. Among other matters, mention is made of the following: The effect of the elements usually present (carbon, sulphur, phosphorus and manganese and silicon); casting chilled test-pieces; the influence of mass and of casting temperature; densening; and the question of machinability.

On the Alloying of Chill and Roll Cast Iron. E. Scharffenberg. (Giesserei, 1935, vol. 22, Jan. 18, pp. 31–35). In the Siegerland, the principal manufacturing district for cast-iron rolls in Germany, the first experiments on the production of alloy chilled cast-iron rolls were undertaken in 1926–27. The author gives an account of the various alloys that were tried out, and their various defects, leading up to an alloy containing 1·32 per cent. of chromium and 4·27 per cent. of nickel, which had the high hardness value of 665 Brinell. The addition of molybdenum as well increased the surface hardness a little further.

Contributions to the Knowledge of Chilled Cast-iron. F. Pohl. (Giesserei, 1935, vol. 22, Jan. 18, pp. 27–31). The author presents details and the results of a research, carried out on high-carbon chill cast iron, in which the two characteristic properties of that material, namely, surface hardness and chill depth, and their double dependence on the chemical composition and the cooling conditions were investigated.

Operations in Making Chilled Car Wheels. R. A. Fiske. (Iron Age, 1935, vol. 135, Apr. 4, pp. 22–26). The plant of the Griffin Wheel Co. described is highly mechanised, and arranged for

continuous operation. A conveyor track links the drag and cope moulding machines with the pouring station and the shake-out pit, whilst the sand from the latter is returned to a storage pit, and so back by conveyor belts to the moulding machines.

Specialises in Jobbing Castings. E. Bremer. (Foundry, 1935, vol. 63, Feb., pp. 26–28, 58). Particulars are given of the methods used at an American foundry for the production of mechanite castings. In the mechanite process from 50–70 per cent. of steel scrap is used in the cupola charge and calcium silicide is added to the molten metal in the ladle.

Ingot Moulds, Bottoms and Slag Ladles. J. Blakiston. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, Feb. 28, pp. 153–154; Mar. 7, pp. 175–176). The layout of a foundry for the production of 400 tons per week of ingot moulds, bottoms and slag ladles is described. Details are provided of the methods of moulding these items of equipment, the type of iron best suited to this class of work is suggested, and the question of mould life touched on.

Indian Foundry Production. W. T. Bruce. (Institute of British Foundrymen: Foundry Trade Journal, 1934, vol. 51, Dec. 20, pp. 387–391). The production of vertically cast pipes is described, and of pile cylinders and screws. Details are also provided of the method of casting sleepers, loam mould castings, sewage, water, and gas pipe fittings, and a number of other items.

Uniformity in Finished Castings. D. R. Kinnell. (Foundry Trade Journal, 1935, vol. 52, Feb. 28, p. 158). Some notes on the production of well-finished cast-iron pipes are given.

The Preparation of the Mould for an Abnormal Branch Pipe of 300/200 mm. Internal Diameter. Löwer. (Röhrenindustrie, 1935, vol. 28, Jan. 11, pp. 6–7). Moulding procedure for making a Y-shaped pipe is illustrated and described.

A New Foundry Product. A. B. Everest. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, Apr. 25, pp. 279–280). The product referred to is the modern permanent magnet, of tungsten, cobalt, or nickel-aluminium steel. These alloys are very difficult to work, and are therefore cast.

Practical Bath Manufacture. (Engineer, 1934, vol. 158. Dec. 7, p. 577). A brief account is given of cupola practice and moulding practice for the production of domestic baths.

Moulding a Steam Cylinder for a Gas Compressor by Means of Loam Patterns. G. Schüle. (Giesserei, 1935, vol. 22, Feb. 1, pp. 55–57).

Production of a Low-Pressure Steam Cylinder by Means of Strickle Boards. F. Vogelsang. (Giesserei, 1935, vol. 22, Jan. 4, pp. 6–10). The author describes in detail the strickle-moulding of a low-pressure steam cylinder.

Manufacture of a Cast-Steel Rotor for a Water Turbine. C. Heiken. (Giesserei, 1934, vol. 21, Dec. 7, pp. 517–520). The making of a 2·4-m. diam. water-turbine rotor is illustrated and described. The buckets are in the form of pressings, and are cast-in into the cast-steel hub and shroud ring. The preparation of the mould, the arrangement of the buckets in their exact positions in it, the casting process and the final cleaning and machining are dealt with.

Water-Turbine Wheels and their Manufacture. F. Paschke. (Giesserei, 1935, vol. 22, May 24, pp. 252–255). An illustrated description is given of the moulding of a water-turbine wheel.

CENTRIFUGAL CASTING.

Nitriding Iron Cast Centrifugally. E. F. Ross. (Foundry, 1935, vol. 63, Mar., pp. 26–27, 62). An outline is given of the production and heat treatment of centrifugally cast nitricastiron at the works of the Forging and Casting Corporation, Ferndale, Michigan.

Centrifugally Cast Electric Cast Iron Pump Piston Cores. A. E. Falk. (Metals and Alloys, 1935, vol. 6, Jan., pp. 7–10). The electric cast iron is derived from remelted borings. The centrifugal device consists of two bowls mounted on opposite ends of a pivoted frame. The moulds are taken to the bowls by a conveyor and the process is continuous. A mould from the track is picked up by a hoist and placed in a bowl; the frame is then revolved through 180°, bringing the empty mould beneath a ladle of molten metal; the iron is poured, the mould spun, the frame turned through 180° and the full mould removed and placed on the conveyor. This cycle is repeated. The moulds, of grey cast iron, are in two halves. The piston cores obtained by this method of casting are stated to withstand rough treatment very successfully.

STEEL FOUNDRY PRACTICE.

Castings. W. Machin and M. C. Oldham. (Institute of British Foundrymen, 1935, Paper No. 567). The authors commence by discussing the methods of feeding steel castings and the defects associated with incorrect feeding. The care which must be taken to ensure a sound casting is emphasised, many examples being quoted, and the excellent results obtainable by the use of high quality cast iron are mentioned. The importance of proper contraction allowance is then dealt with; this is especially

important in the case of large steel castings. Several such castings are discussed in detail, including a steel propeller shaft bracket, a cast steel stern frame, and a cast steel rudder frame weighing 13½ tons. Attention is directed to the necessity for providing cores which will be weak enough to contract with the casting as it cools, and feeding heads of ample size and careful design. It is pointed out that annealing greatly improves large castings, but the process must be cautiously carried out. Many of the more serious defects in steel castings are critically examined, and suggestions are made for their avoidance. The authors' remarks are accompanied by numerous illustrations.

The Steel Foundry. C. W. D. Townsend. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 175–178). Among other matters, the author deals with the physico-chemical equilibria and fluidity of molten steel, and the properties of foundry sands. The use of chills is discussed, together with the question of steel melting.

Green Sands for Steel Castings. W. Rose. (Foundry, 1935, vol. 63, Mar., pp. 24–25, 60). The author discusses the use of green sand in the moulding of steel castings.

MALLEABLE CAST IRON.

Some Facts about the Material Malleable Cast Iron of Use to Makers and Users. H. Dittmar. (Giesserei, 1935, vol. 22, Apr. 26, pp. 189–194). After discussing the disadvantageous effect of the German Standard DIN 1692 for malleable cast iron and efforts for its alteration, the author deals with the production and development of this material, presents observations from practice in the manufacture of whiteheart malleable, and discusses the conditions for the use of whiteheart and blackheart malleable. He also touches on the weldability of whiteheart malleable.

Short-Cycle Malleable Iron Reduces Machining Costs. J. M. Highducheck. (Steel, 1935, vol. 96, May 6, pp. 51–52). Examples are cited of malleable castings which were difficult to machine. Tests were carried out on ordinary malleable castings and castings malleablised by the short-cycle electric process; the castings produced by the new method were much easier to machine.

FOUNDRY PLANT.

The Roll Foundry of C. Akrill and Co., Ltd. (Iron and Coal Trades Review, 1935, vol. 130, Jan. 18, pp. 134–135). The equipment of the Gold's Green Foundry of this company is described and illustrated.

Foundry Doubles Plant Capacity. P. Dwyer. (Foundry, 1934, vol. 62, Dec., pp. 20–22, 55). An account is given of moulding practice at the foundry of the Chevrolet Co., Saginaw, Michigan.

Some Observations on Foundry Planning. A. N. Harley. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, May 23, p. 342). Some of the points which are important in proper foundry organisation are briefly considered.

Some General Remarks on Mechanised Foundries and the Making of Motor Cylinders. G. W. Brown. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, Mar. 14, pp. 183–184, 198; Mar. 21, pp. 205–207). A description is given of much of the mechanical foundry plant at a large motor works. The core-making and core-drying equipment is described, together with the mould conveyor, knock-out machines, and fettling and cleaning devices.

Modern Foundry Transport. H. Schulze-Manitius. (Giesserei, 1935, vol. 22, Mar. 15, pp. 133–136). After stressing the need for conveyors in foundries, the author gives details of a plant with two conveyors arranged one above the other, a used sand plant and its conveying system, and a conveyor consisting of trucks running on rails.

Foundry Plant and Machinery. (Metallurgia, 1935, vol. 11, Feb., pp. 90–92). This article is a brief review of certain items of equipment, such as conveyors, moulding machines, and the cupola.

Selecting Foundry Conveying Equipment. R. J. Heisserman. (Fifth International Foundry Congress: Foundry Trade Journal, 1935, vol. 52, Jan. 24, pp. 73, 74, 82). The author discusses the considerations which govern the selection of conveying equipment.

COOLING PHENOMENA AND DEFECTS IN CASTINGS.

Defects in Iron Castings: Their Cause and Cure. T. Tyrie. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, Jan. 17, pp. 59–62; Jan. 24, pp. 77–80). The results of critical examination of various types of defect are presented. The defects are considered to arise from four sources, namely, metal, sand, moulding practice and design. Examples of particular flaws are examined in detail.

A Review of Factors Influencing the Soundness and Solidity of Grey-Iron Castings. J. L. Francis. (Foundry Trade Journal, 1935, vol. 52, May 2, pp. 295–297). The principal factors appear to be: Dissolved gases (due to poor cupola practice); shrinkage on solidification; casting temperature (including degree of superheat, if any); the placing of runners and risers, and the

use of feeders; the employment of denseners; the question of design; the composition of the pig iron, and of the grey cast iron obtained from it.

The Shrinkage of Castings and its Effects. E. Scheuer. (Metallwirtschaft, 1935, vol. 14, May 3, pp. 337–344; May 10, pp. 365–367). The author discusses the nature of the shrinkage of castings, and then deals with the influence of the temperature distribution, of the alloying elements, and of gases, the formation of fissures, and the effect of cavities on the mechanical properties. In illustration of his remarks the author makes reference mostly to non-ferrous alloys.

Controlled Directional Solidification. G. Batty. (Transactions of the American Foundrymen's Association, 1935, vol. 6, Feb., pp. 237–264). The author shows that simple gravitation of metal superimposed as feeder heads will not in many cases produce soundness in steel castings. Correctly disposed temperature gradients in both mould and metal are essential pre-requisites to the proper functioning of gravitational feeding. Specially designed gating and heading procedure, together with details of mould manipulation, are described and the relation of moulding materials to pouring temperature and pouring speed is discussed.

Further Notes on Defects in Steel Castings. C. Howell Kain. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, Feb. 21, pp. 139–141). The causes of cracks are examined in detail, and the use of pencil gates is referred to. Suggestions are made concerning the causes of blowholes and laps.

Free and Hindered Contraction of Cast Carbon Steel. C. W. Briggs and R. A. Gezelius. (Transactions of the American Foundrymen's Association, 1934, vol. 42, pp. 449–476, Foundry Trade Journal, 1935, vol. 52, Mar. 28, pp. 217–218). Round bars were cast in such a way that, with suitable devices, the contraction and temperature could be recorded. Electric steel was used to cast the bars, which were of a carbon content varying from 0·08 to 0·90 per cent. The contraction was 2·47 per cent. for the former steel and 2·18 per cent. for the latter, in the case of free contraction. Tests were also carried out on bars subjected to hindered contraction by using a spring to restrain the contraction of the bars.

Preparation of Steel to Avoid Porosity in Castings. C. E. Sims. (Transaction of the American Foundrymen's Association, 1934, vol. 42, pp. 323–338). For the prevention of porosity in steel castings, the dissolved gases in the steel should be reduced to the lowest possible content, and conditions produced for the retention of gases in solid solution. Conditions favouring low gas content are a long vigorous boil, thorough oxidation, low residual silicon and manganese, moderate temperatures, late

oxidation, and no temperature increase after deoxidation. Conditions favouring retention of gases in solid solution during freezing are thorough deoxidation and a minimum exposure after deoxidation.

The Relation of Moulds and Cores to Porosity in Steel Castings. G. Batty. (Transactions of the American Foundrymen's Association, 1934, vol. 42, pp. 339–363). The author outlines the properties of sands for green, skin-dried and dry-sand moulding and points out that the expansion of the interspacial atmosphere and the gases given off by the binders are two causes of porosity. He stresses the importance of the permeability of backing sands and explains why such sands should be of higher permeability than the facing sands. The effect of various systems of moulding on porosity and the effect of flask and jacket equipment are discussed in relation to the promotion of porosity. The author urges the use of specially prepared gate cores as a remedy for certain types of porosity and explains how they are made and how moulding procedure can be changed to make use of them.

Function of the Steel Foundry Foreman in Preventing Porosity. R. A. Bull. (Transactions of the American Foundrymen's Association, 1934, vol. 42, pp. 375–393). The question of porosity is first discussed in a general way, and the author continues by enumerating the conditions which are likely to give rise to porosity. Among the relevant factors are: Insufficient drying of ladles, inadequate degasification, exposure of tapped metal to the atmosphere, and defects connected with the mould itself.

PRODUCTION OF STEEL.

STEEL-MAKING PRACTICE.

Applications of Science to the Making and Finishing of Steel. J. Johnston. (Mechanical Engineering, 1935, vol. 57, Feb., pp. 79–86). The author reviews the present scope of the application of science to the production of steel, and puts forward suggestions for future development; he makes observations concerning the present practice of steel melting, and the reliance to be placed on the various mechanical tests.

Science as a Practical Aid to the Steelmelter. J. W. Bell. (Iron and Steel Industry, 1935, vol. 8, Mar., pp. 245–246). The author suggests that a knowledge of the scientific principles of steelmaking may well prove advantageous to steel melters.

Modern Crucible Melting Equipment. R. H. Stone. (Industrial Heating, 1935, vol. 2, Apr., pp. 181–186). A brief illustrated account is given of modern developments and methods in crucible melting practice.

Modern Equipment used in Crucible Melting. R. H. Stone. (Transactions of the American Foundrymen's Association, 1935, vol. 6, Feb., pp. 265–288). The author discusses a number of aspects of crucible furnace practice, including types of fuels and refractories. Several typical crucible furnace installations are described.

The Manufacture of Tool Steel. J. H. Hruska. (Heat Treating and Forging, 1934, vol. 20, Nov., pp. 538–541). An outline is given of melting and teeming practice for the production of high-carbon steel in crucible and high-frequency furnaces.

American Tool Steels. Manufacture and Testing. J. P. Gill. (Metal Progress, 1934, vol. 26, Nov., pp. 42–46). In the U.S.A. the crucible process is almost obsolete; the basic open-hearth process is mainly used for low-alloy steels, whilst the basic electric-arc furnace is the most widely employed; the induction furnace accounts for only a small tonnage. The steels require special care in casting, forging, rolling and heat-treating. The salient characteristics of American tool steels show wide variations, whilst hardness, abrasion, and other tests are seldom strictly comparable. Tests for hardening distortion, hardenability, and uniformity are sometimes applied, in addition to the usual machining trials.

Investigations on the Most Suitable Shape of the Basic Bessemer Converter. T. Heyden. (Stahl und Eisen, 1934, vol. 54, Nov. 29,

pp. 1225–1230; Dec. 6, pp. 1256–1259). Investigations on the wear of the lining and the change of shape of the converter during a campaign were carried out on two converters, one with a cylindrical and the other with an oval cross-section. The tests showed that the wear of the lining was not uniform over the whole circumference; it was much greater on the back than on the belly, and this caused a displacement of the reaction space towards the back. Further, it was found that the flow conditions were influenced in the same sense much more strongly in the oval than in the cylindrical form of converter. During each campaign of the two converters, graduated charges were blown at the commencement and end of the life of each bottom, in order to discover the connection between the charge weight, time of blowing and blast consumption on the one hand and the dimensions and shape of the interior of the converter on the other. A comparison of the results obtained revealed that the converter with oval cross-section operated more satisfactorily. The observations showed that the determination of the circulation cross-section must be based on the greatest surface of the reaction space. Other tests showed the relationship between the blowing time and the consumption of dolomite. Finally, the importance of the height of the converter in regard to the conditions within it are discussed, and the mechanical processes taking place in the converter during the passage of the blast are described.

Relations Between the Blowing Period in the Basic Bessemer Converter and the Output in the Dressing Shop. R. Frerich and T. Lütgen. (Stahl und Eisen, 1934, vol. 54, Dec. 27, pp. 1329–1332). The authors present the results of an investigation in which observations were made of the output, use of scrap, charge weight and blowing time during the campaign of two basic converters. They show the influence of the blowing time on the outputs from the converter shop and from the dressing shop and on the total output; they also indicate the effects of the temperature and silicon contents of the basic pig iron and also of the capacity of the mixer on the period of the blow and on the output. The blowing time is closely related to the output, and from it the operator can draw important conclusions regarding the quality of the steel produced.

The Lining and Maintenance Costs of Open-Hearth Furnaces. F. W. Morawa. (Stahl und Eisen, 1935, vol. 55, May 9, pp. 509–515). In the open-hearth furnace, the functions, duties and wear of the various furnace parts during a campaign, and, therefore, the costs for the various parts, are very different. By means of cost records extending over several years, the author explains how the total costs for the furnace are distributed between the individual items. He shows that the various operating conditions, determined, for instance, by the combustion or

charging conditions required by the state of the pig iron or scrap, are not without influence on the life of the furnace, and, therefore, on the maintenance and repair costs.

Furnace Efficiency Increased by Moll Checkers. P. Stickel. (Blast-Furnace and Steel Plant, 1934, vol. 22, Nov., pp. 635–637). Particulars are given of the Moll oval-shaped checker brick for open-hearth furnace regenerators, and its advantages are pointed out.

Infiltered Air in the Hearth of the Open-Hearth Furnace, Its Effect and Prevention. G. Köhler. (Stahl und Eisen, 1935, vol. 55, Apr. 4, pp. 383–391). The purpose of the investigation described by the author was to determine the proportion of air infiltering into the hearth of an open-hearth furnace in relation to the total amount of air, its variation during the campaign of the furnace, and the effect on it of variations in the working of the furnace. The proportion of infiltered air under normal working conditions was determined thus : The chimney draught was throttled down until the pressure in the hearth was sufficient to prevent the infiltration of air. Samples of waste gas were then drawn under this condition and during normal operation, and the proportion of infiltered air in the latter case was calculated from the analyses. The research revealed that after a preliminary increase in the amount of infiltered air, for which no adequate explanation is offered, the value remained fairly constant during the furnace campaign, until the end when, probably on account of marked increase of pressure in the hearth due to increasing resistance in the regenerators, it tended towards a minimum value ; this shows that the decrease of furnace efficiency towards the end of the campaign is not connected with any increase of air infiltration. Careful adjustment of the chimney draught had a very notable influence on the air-gas mixture and the infiltered air ; but the limits of control so attainable were not all that could be desired, owing to difficulties associated with the loss of heat in flames issuing from the furnace ; for complete success, reconstruction of the furnace to make it completely " tight " would have been necessary. It was determined that by the prevention of air infiltration an economy of 14 per cent. of the total heat expended could be attained.

New Metal Mixer at Scunthorpe. (Iron and Coal Trades Review, 1935, vol. 130, Feb. 22, p. 334). Illustrated particulars are given of the 400-ton mixer in operation at the Normanby Park Steelworks of John Lysaght, Ltd., Scunthorpe. The chief features are as follows : Length over chills, 55 ft. 6 in. ; bath at metal level, 46 ft. long by 15 ft. 6 in. wide with a maximum depth of 4 ft. 6 in. The mixer is tilted by means of a 95-H.P. motor direct-coupled to worm reduction gear, then through spur gears driving on to racks which are attached to the rocker

heads, giving a speed on the roller path of 10 ft. per min. The angle through which the mixer turns is 25° on the pouring side and 15° on the slagging side. The port ends are of the " Wellman-Soward " type, designed for the use of mixed gas. Gas and air regenerators are provided, having a total checker capacity of 5,870 cu. ft. on each side. The mixer can be used for melting up to 20 per cent. of its throughput of cold pig and scrap when desired.

Modern Trend of Steel Melting Practice. T. M. Service. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 179–182, 212). Present-day practice favours a furnace of 60 tons capacity for open-hearth furnaces. Attempts to improve efficiency and reduce maintenance, have, in America and on the Continent, led to the use of cooled and interchangeable port ends, and to the adoption of Venturi furnaces. The greater use of alloy steels has encouraged the electric-melting process.

Ladle and Teeming Practice in the Open-Hearth Department. G. D. Tranter. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 618). The author gives an account of the factors bearing upon the operation of teeming rimming steel. Details such as the refractories used in the ladle, the stopper-rod assembly, the size of nozzle, rate of teeming and design of ladle are dealt with, whilst the effects upon the ingot of the type of mould and method of pouring are examined. Some attention is paid to the technique of pouring, and the importance of correct organisation and manipulation is stressed.

A Special Application of the " Monell Process " for Steel Making in a Stationary Basic Open-Hearth Furnace. A. E. Dobner. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1935, vol, 35, Feb., pp. 253–265). The author describes a modification of the Monell process of steel making which he terms the " Trade Heat " method. In the modified method the proportion of liquid metal in the charge is much less than that in the original. Particulars are given showing the make-up of nine regular charges. The working procedure of a charge is discussed in detail and the course of the reactions is briefly considered.

Production in the Basic Open-Hearth Furnace of High-Quality Steel for Deep Drawing. T. G. Grey-Davies. (Sheet Metal Industries, 1935, vol. 9, May, pp. 281–282). The author suggests a combination of the basic Bessemer and open-hearth processes for the production of steel for cold-pressing and deep drawing. The possibilities of an open-hearth furnace equipped with air blast for effecting the rapid removal of carbon and phosphorus are outlined.

The History of the Duplex Process. P. Eyermann. (Eisenhütte Oesterreich, Apr. 28, 1934: Stahl und Eisen, 1934, vol. 54,

Dec. 20, pp. 1320–1321). The Bessemer process was introduced in Neuberg, Styria, in 1864, and the open-hearth process in 1870. In 1872 the duplex process was suggested by F. Lang as a means of speeding up production, the metal being first refined in the converter and then finished in the open-hearth. The author states that the use of liquid pig iron in the converter direct from the blast-furnace, the setting of the air and gas chambers for the open-hearth below floor level, but behind the furnace, and the duplex process were all introduced at Neuberg before they found application in America. One advantage of the duplex process was that owing to the suppression of piping in the ingot, the discard of one-third to one-half of the top of the ingot when making steel for ordnance became unnecessary. It is also stated that attempts to press ingots while still liquid in part were made long before Harmet put forward his proposition.

The Heat Exchanges in the Hearth of the Open-Hearth Furnace. H. Malcor. (Chaleur et Industrie, 1934, vol. 15, Nov., pp. 338–340). The author discusses the exchanges of heat which take place within the open-hearth ; he deals only with the later part of the refining process after all the scrap in the charge has melted, because the surfaces across which the heat exchange between flames and bath occur have then become simply the surface of the bath itself. In the early stage of the process, convection plays a more important part.

Chemistry of an Open-Hearth Heat. L. H. Nelson. (Blast Furnace and Steel Plant, 1934, vol. 22, Dec., pp. 687–688, 698 ; 1935, vol. 23, Jan., pp. 126–128, 136 ; Feb., pp. 126–128, 136, 150). The author discusses the chemical reactions taking place in the basic open-hearth process from the time the heat is charged until it is tapped in the ladle.

Investigations on the Course of the Metallurgical Reactions in the Acid Open-Hearth Process. P. Bardenheuer and G. Thanheiser. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1934, vol. 16, No. 17, pp. 189–200). The concentration changes taking place in the bath and slag in the acid open-hearth were investigated ; in three cases the charges were solid and in two they were added in the molten condition. A characteristic throughout these experiments was the very great reduction of silicon which was attained. The manganese content altered only in the early stages, while chromium, nickel, molybdenum, phosphorus, and sulphur hardly varied throughout the whole working period. The oxygen content remained very low throughout, and was much below what might have been expected from the ferrous oxide contents of the slags. Comparative hot-extraction and chlorine-residue determinations of the oxygen in the solid steel showed that it was mostly combined with silicon. The behaviour of nitrogen was noteworthy. In all cases where

solid charges were used, the nitrogen content decreased during the heat; with molten charges, in some cases it decreased only slightly and in others it increased. At the commencement of the heat the nitrogen was higher with solid than with molten charges.

In all cases the silica contents of the slag rose to about 57 per cent. The iron was mostly present as ferrous oxide, but the content of the latter was very variable; in the first samples from the heats it lay between 36 and 38 per cent., in the last ones between 9 and 23 per cent. The effect of the ferrous oxide during the working period was not uniform, decreasing in some cases and increasing in others. In all the slags, the manganous oxide content decreased as time went on. Chromium was found in variable quantities, and nickel and molybdenum hardly at all.

At the beginning of the heat, the manganese and silicon reactions tended towards equilibrium, as had been found in an investigation of the pure systems; later the equilibrium was disturbed by the carbon of the bath. Owing to the great rate of reduction of the carbon, the oxygen is removed from the bath more rapidly than it can be returned to it by diffusion from the slag. With viscous slags, the slag layer in contact with the iron becomes impoverished in ferrous and manganous oxides, so that a layer of solid silica forms between the slag and the metal. The silicon content of the bath then rises above the value corresponding to equilibrium with the slag, and, finally, reaction between the bath and slag almost ceases. If the bath comes into contact with slag containing ferrous and manganous oxides, the ferrous oxide is reduced by the silicon to form silica and the barrier between slag and metal is renewed. For this reason, towards the end of the heat the rate of carbon reduction is determined almost exclusively by the silicon reduction.

Deoxidation of Steel. E. Gregory. (Iron and Steel Industry, 1935, vol. 8, Apr., pp. 279–281). It is pointed out that the addition of deoxidising agents results in the production of high-melting-point oxides which give rise to inclusions. If ternary or more complex ferro-alloys are used the deoxidation products will remain molten when the steel commences to freeze, and oxide inclusions will not tend to separate out. At the same time, temperature appears to exert an effect (largely unknown) on the deoxidising power of silicon and manganese, &c. Furnace temperatures are not easily measured, and practical men have devised many empirical methods of temperature estimation.

Titanium—Its Uses in Metallurgy. P. M. Tyler. (Metals and Alloys, 1935, vol. 6, Apr., pp. 93–96). Among other matters, reference is made to the part played by titanium in the production of steel, notably its use as a deoxidiser, and for the purpose of carbide control.

The Perrin Process of Steelmaking. W. D. Pugh. (Iron and Steel Industry, 1935, vol. 8, Apr., pp. 275–279). This process has, as its main object, the dephosphorisation of steel, and this is attained by pouring the steel into a ladle containing a synthetic basic slag. The mixing of slag and metal must be very intimate and is brought about by rapidly pouring the steel from a height of about 20 ft. into the molten slag. But the method may also be applied to the deoxidation of steel, in which case an acid slag is used in order to remove FeO. Ferro-manganese may be added, when some of the FeO is replaced by MnO, which dissolves more readily in the slag. The process has been applied to duplex operation (basic converter—electric furnace) with success.

Reflections on the Desulphurisation of Steel. M. Guédras. (Aciers Spéciaux, 1934, vol. 9, Nov., pp. 627–628). A brief discussion of the reactions concerned in, and the conditions required for the desulphurisation of steel, with particular reference to the electric steel furnace.

The Equilibrium FeS + Mn ⇌ MnS + Fe at High Temperatures. O. Meyer and F. Schulte. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Nov., pp. 187–195). By melting together mixtures of iron, manganese and manganese sulphide, and of iron, manganese and iron sulphide, and quenching the products after the attainment of equilibrium, the authors have made an investigation of the equilibrium between iron, manganese and their sulphides, which was approached from both sides. It was found that over a wide range of concentrations the equilibrium between manganiferous iron melts and pure sulphide slags could be well represented by the equations:

$$K_1=\frac{(\mathrm{Fe})\times[\mathrm{Mn}]}{(\mathrm{Mn})\times[\mathrm{Fe}]} \text{ and } K_2=\frac{[\mathrm{S}]\times[\mathrm{Mn}]}{(\mathrm{S})\times[\mathrm{Fe}]}$$

At a temperature of 1,600° C., $K_1 = 0{\cdot}00425 \pm 0{\cdot}00125$, and $K_2 = 0{\cdot}000725 \pm 0{\cdot}000175$. Additions of carbon and silicon to the molten metal influenced essentially only the K_2 value. The heat evolutions, calculated from the dependence of the equilibrium constant K_1 on the temperature, worked out to 18–19 k.-cal. per mol. The experiments showed, further, that the miscibility gap at 1,600° in pure iron-manganese melts containing sulphur was indicated by manganese and sulphur contents in the molten metal the product of which averaged $[\mathrm{Mn}] \times [\mathrm{S}] = 2{\cdot}6$. In melts containing carbon this value dropped to 1·2 and in the temperature range 1,350° to 1,250° it decreased to 0·75. Desulphurisation of metal baths on a practical scale by segregation of pure sulphides is therefore not to be expected at these temperatures.

Oxide Impurities in Steel. F. Körber. (Zeitschrift für Metallkunde, 1934, vol. 26, Nov., pp. 241–244). In this review of the

non-metallic impurities in steel, the author deals with the solubility of oxides in molten and solidified steel and means for reducing the oxide content of the metal (lowering the ferrous oxide content of the slag, and the use of deoxidisers). He also presents and discusses diagrams showing the deoxidation of steel by manganese and silicon.

The Control of Iron Oxide in the Basic Open-Hearth Process. C. H. Herty, jun., C. F. Christopher, H. Freeman, and J. F. Sanderson. (Mining and Metallurgical Investigations, 1934, Co-operative Bulletin No. 68). This bulletin contains the results of experimental work on the control of iron oxide in the slag and metal in high- and low-carbon steels. The basic open-hearth process is dealt with, and a detailed discussion of the theory of the slag and metal reactions, with special reference to the influence of iron oxide, is given. A relation is found to exist between the basicity of the slag and the iron oxide contained therein, whilst the influence of this oxide upon the oxidation of the metal may be represented by a linear function. In order to determine the viscosity of the slags a new viscosimeter was developed. Slag fluidity and basicity are found to have a strong influence upon the course of the reactions in the furnace. It is concluded that iron oxide in basic open-hearth slags may be controlled within close limits, the two most important factors being fluidity and basicity. As the basicity increases the available iron oxide in the slag decreases, and the FeO content of the metal is directly proportional to the available iron oxide content of the slag.

The Physical Chemistry of Steel Making. S. Epstein. (Metals and Alloys, 1935, vol. 6, Mar., pp. 71–77). This article deals with basic open-hearth practice, and gives a résumé of work done in recent years by Herty. The problem of FeO control is discussed and the purpose of slag adjustment is considered. Attention is then paid to the FeO content in the slag and the effect of ferrous oxide in the metal. The problem of the deoxidation of steel is dealt with and there follows a discussion of grain size and of ageing in mild steels.

An Investigation into the Oxidising Power of Basic Slags. J. White, R. Graham and R. Hay. (Iron and Steel Institute, May, 1935; this Journal, p. 91).

Slag Control in Steel Making. (Metal Progress, 1934, vol. 26, Dec., pp. 40–42, 44, 48). This article is a report of a symposium on slag control. Specific details are supplied of the slags used for the production of rimming ingots, killed steel high in carbon, and rail steel. Considerable attention is devoted to the problem of the FeO in the slag, and the ways of controlling slag composition. Mention is made of electric furnace operation.

Estimating Open-Hearth Slag Composition. I. N. Goff. (Blast-Furnace and Steel Plant, 1934, vol. 22, Nov., pp. 640–641,

656 ; Dec., pp. 693–694). The author discusses methods available for determining slag conditions in an open-hearth heat. Methods are suggested for the determination of FeO, Fe_2O_3, MnO and the specific gravity. Descriptions of the methods are given and comments are made on their accuracy. It is suggested that the balance of the slag composition can be estimated by reference to prepared charts.

Equilibria between Metals and Slags in the Molten State. W. Krings. (Zeitschrift für Metallkunde, 1934, vol. 26, Nov., pp. 247–249). By reference to examples of well substantiated and technically important equilibria between metals and slags in the molten condition, the author discusses the question how far the law of mass action is applicable to such equilibria and what conclusions regarding the state of the molten metal and slag, in particular, the presence of particular molecular types and their dissociation relationships, can be drawn.

The Equilibrium between Carbon and Oxygen in Molten Steel. H. Wentrup. (Stahl und Eisen, 1934, vol. 54, Nov. 22, pp. 1216–1217). A short review of published information.

The Brackelsberg Furnace. W. Alberts. (Heat Treating and Forging, 1935, vol. 21, Feb., pp. 94–97 ; Mar., pp. 141–143). The Brackelsberg furnace is described and the results obtained with it in the melting of steel are presented.

The Reactance of Large Rectangular Three-Phase Furnaces. F. V. Andreae. (Electrochemical Society, 1935, Mar., Preprint 67–16). In the case of large rectangular three-phase furnaces, unbalance is likely to occur as a consequence of the disposition of the conductors (leading to differences of mutual reactance between the phases) and the self-reactances of each phase. The author analyses this problem and presents tables which permit the furnace designer to determine the reactance of a furnace of given dimensions and to calculate its characteristics.

Steel Melting. J. Dummelow. (Electrician, 1934, vol. 113, Nov. 9, pp. 605–607). The author describes the advantages of the Witton induction furnace for the melting and refining of steel. It differs from previous designs in that the induction coil is surrounded by steel laminations which also project a short distance into the bottom of the crucible ; this ensures a strong field in the centre of the charge, thus increasing the speed of melting, and also practically eliminates stray fields.

The Development of the Submerged Resistor Induction Furnace. G. H. Clamer. (Metals and Alloys, 1934, vol. 5, Nov., pp. 242–250). In this article the history of the submerged resistor furnace is narrated. The difficulties encountered were many. Early attempts to use a resistor of molten metal were unsuccessful owing to heavy heat losses from the electrodes and pinch, skin, and motor effects. When electrodes were dispensed with and the

principle of induction was applied progress was rapid and the Ajax-Wyatt furnace was developed ; this made use of the pinch and motor effects.

High-Frequency Furnaces. T. Swinden. (Iron and Coal Trades Review, 1935, vol. 130, Jan. 11, pp. 83, 84). A review of the progress made in the production of high grade steels in high-frequency furnaces during the past year.

High-Frequency Induction Furnaces in Modern Metallurgical Practice. N. Frati. (Elettrotecnica, 1934, vol. 21, Dec. 15, pp. 828–832). A distinction is made between furnaces employing a magnetic core carrying the primary winding with the material to be melted forming a closed secondary circuit, and those in which there is no core and the primary winding is placed outside the crucible containing the metal. The author describes the latter type and gives particulars of the electrical equipment.

Theory of the High-Frequency Furnace. M. Mathieu. (Arts et Métiers, 1935, vol. 88, Mar., pp. 46–52). The author discusses the theory of the electrical characteristics of the high-frequency furnace with conducting crucible, by considering it as a transformer without magnetic circuit.

Calculations for Coreless Induction Furnaces. H. B. Dwight and M. M. Bagai. (Electrical Engineering, 1935, vol. 54, Mar., pp. 312–315). Calculations of the electrical characteristics of coreless induction furnaces are usually made by means of the penetration formula (equation 18 in the present paper) ; this formula, however, gives only an approximation, which is fairly accurate only at relatively high frequencies. As a wide range of frequencies can be used in these furnaces, there is a need for calculations that are valid at any frequency ; to meet this need the fundamental calculations upon which the penetration formula is based are presented.

Comparison of High-Speed Steels made in the Coreless Induction Furnace and in the Arc Furnace. E. Houdremont, H. Kallen, and K. Gebhard. (Stahl und Eisen, 1935, vol. 55, Feb. 28, pp. 228–234). High-speed steels containing (*a*) tungsten 18, chromium 4, and vanadium 1 per cent., and (*b*) tungsten 14, chromium 4, and vanadium 2 per cent., some with molybdenum and cobalt additions as well, were made in 50- and 1,000-kg. high-frequency furnaces and their properties compared with those of similar materials produced in the arc furnace, in order to determine whether there were any basic differences between them. It appeared that the carbide distribution was more suitable in the high-frequency steel, but the hardness, stability on tempering and durability in cutting were no greater than those of arc-furnace steel. In these tests the influence of the type and operation of the furnace and of the charge material was masked by the effects of the alloying elements.

SLAGS.

Notes on the Basic Open-Hearth Process. J. M. Ferguson. (Journal of the West of Scotland Iron and Steel Institute, 1934, vol. 42, Nov., pp. 13–20). In the main, the author discusses the microscopic examination of basic slags. Slag sections were prepared and examined by transmitted and reflected light. The petrographic features are detailed and supplemented by chemical analyses. Crystals of tribasic ferrite and tricalcic silicate were among those identified. Slags present during the cutting-down stage show the existence of magnetic constituents ; slags from the melting stage reveal the presence of dicalcic silicates ; whilst tricalcic silicates occur in the finishing stages. The author makes certain deductions on the basis of his investigations ; his remarks are illustrated with photographs.

Slags as Nitrogen Carriers. W. Eilender and O. Meyer. (Stahl und Eisen, 1935, vol. 55, May 2, pp. 491–493). The nitrogen contents of slags of all kinds from iron and steel works were determined. The attempt was made to discover a regular relationship between the nitrogen in the slag, that in the metal and the slag composition. The experiments, however, gave no clear indication of any "nitrogen equilibrium" between the slag and the metal.

The Ternary System FeO-CaO-SiO_2. M. Moray. (Revue Universelle des Mines, 1935, vol. 11, Mar., pp. 141–152). The author presents a critical review of the work of numerous investigators who have carried out researches on this and related systems ; a list of thirty-three references is given.

The Iron/Iron-Oxide/Calcium-Orthoferrite System. E. Martin and R. Vogel. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Dec., pp. 249–254). Iron, iron oxide and lime were melted together in a platinum crucible ; cooling curves were then taken, and the structures of the resulting solidified masses were examined. In the range examined, $(CaO)_2.Fe_2O_3$–$CaO.(FeO)_9$–Wüstite-Fe_3O_4–$CaO.Fe_2O_3$, two new types of crystal were found ; one very probably corresponds to the formula $CaO.(FeO)_9$, and the other to $(CaO)_4(Fe_3O_4)_3$. These two compounds divide the range investigated into five three-phase and one two-phase ranges. Free iron occurred on crossing the section $(CaO)_2.Fe_2O_3$–$CaO.(FeO)_9$ and $CaO.(FeO)_9$–Wüstite in the direction of higher iron contents. Free lime, together with free iron, was found in specimens which contained more lime than corresponds to the section iron–$(CaO)_2.Fe_2O_3$.

STEELWORKS MACHINERY.

Electric Overhead Travelling Cranes. R. J. Harry. (Iron and Steel Engineer, 1935, vol. 12, Feb., pp. 84–103). The author

discusses some of the new developments incorporated in overhead crane design.

Combination Stripper and Extractor Crane. (Iron and Coal Trades Review, 1935, vol. 130, Mar. 15, p. 462). Brief particulars are given of a combination stripper and crane of American design for the stripping of ingots. The machine exerts a stripping force of 150 tons and can handle either big-end-down or inverted types of moulds. The trolley of the crane operates on a bridge of 70 ft. span.

CASTING AND TREATMENT OF INGOTS.

Finishing the Heat of Steel. J. H. Hruska. (Blast-Furnace and Steel Plant, 1934, vol. 22, Nov., pp. 638–639, 643 ; Dec., pp. 699–701 ; 1935, vol. 23, Jan., pp. 67–68 ; Feb., pp. 124–125 ; Mar., pp. 197, 200 ; Apr., pp. 257–260). The author continues his discussion of the solidification of steel ingots. He deals with segregation, the influence of mould thickness upon ingot structure, inclusions in ingots, the crystalline structure of ingots and the physical and chemical properties of rimmed ingots (*see* Journ. I. and S.I., 1934, No. II. p. 566).

Segregation of Ingots in Nickel-Alloy Steel Forgings. T. Fujiwara. (Japan Nickel Review, 1935, vol. 3, Apr., pp. 175–178). The author shows that the degree of segregation increases with the size of the ingot, for carbon, phosphorus and sulphur, whereas silicon, manganese, nickel, chromium and copper segregate but slightly with increase in ingot size. Corner-ghost segregation always exists in the larger ingots ; the segregate is high in sulphur and phosphorus. Vertical-ghost, ring-ghost and V-ghost segregation also occurs. Blowholes tend to vary inversely as the extent of piping. With alloy-steel ingots the segregate tends to move towards the centre of the ingot ; in such cases it may be removed by trepanning, and the subsequent forging will be very free from segregation.

The Conditions for the Occurrence of Flakes in Steel. E. Houdremont and H. Korschan. (Stahl und Eisen, 1935, vol. 55, Mar. 14, pp. 297–304 : Technische Mitteilungen Krupp, 1935, vol. 3, Apr., pp. 63–73). Flakes in steel consist of fissures which form after hot deformation and take a course independent of the grain boundaries. In the literature various causes have been suggested for their occurrence : Stresses due to uneven cooling ; the process of deformation ; transformations ; or metallurgical influences such as segregation, impurities and gases, &c. According to the authors' investigation of the conditions giving rise to flakes, they may occur in steels of various compositions. Regarding the influence of the mode of manufacture of the steel on the tendency

to fissuring, crucible steel, acid open-hearth steel and acid high-frequency steel are less liable to this defect than basic open-hearth and electric arc steels. The tendency to flaking increases with the dimensions of the ingot, and the temperature and rate of casting; the use of mould coatings containing hydrogen also promotes it. The bottom of the ingot is less susceptible than the top. Slow cooling and increasing working help to prevent flakes. The experiments showed that the flakes formed in the worked metal during cooling, depending indeed on the rate at which the temperature passed through the range about 200° C. Flakes already formed can be caused to disappear again by further working. The tests show that deformation and transformation stresses, segregates, gas inclusions, &c., alone are insufficient to set up flakes.

The Cause of the Occurrence of Flakes in Steel. H. Bennek, H. Schenck and H. Müller. (Stahl und Eisen, 1935, vol. 55, Mar. 21, pp. 321–328: Technische Mitteilungen Krupp, 1935, vol. 3, Apr., pp. 74–86). Following the conditions determined by Houdremont and Korschan for the occurrence of flakes in steel (*see* preceding abstract), the authors attempted to prove that in hot-worked steel this phenomenon is exclusively an outcome of the pressure generated by the separation of a gas, namely, hydrogen, from solid solution. Flakes could be caused to appear at will in the experimental ingots only by the introduction of hydrogen; oxygen and nitrogen acted differently—they gave rise to blow-holes and consequently a worked piece gave a type of conchoidal fracture, but no flakes. Heat and transformation stresses could favour the formation of flakes but could not actually cause them, and they influenced in general only the position and direction of the flakes in the worked metal. Further, grounds were discovered for the opinion that other types of fissure—primary grain-boundary cracks, conchoidal fracture, stress cracks—are also caused essentially through the separation of hydrogen out of solid solution. This noxious effect of hydrogen is not restricted to steels said to be liable to flakes; it occurs in similar or comparable forms in other alloys, probably in all steels. The known measures for combating the danger of flakes all bring about one of two effects in the steel; either they reduce the hydrogen content (suitable furnace operation, low casting temperature, low hydrogen content in the mould wash), or they favour the diffusion of hydrogen in the worked piece; to the latter category belong the slow cooling of the piece, reheating and long annealing before working, &c.

Spectro-Analytical Investigations on Flakes in Chromium-Nickel Steels. H. Esser, W. Eilender, and A. Bungeroth. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Mar., pp. 419–423). By X-ray and optical spectral analyses on flaky chromium-nickel steels the authors were able to prove that thin layers, rich in

chromium, nickel and manganese, were present in the surfaces of the flakes. The observed decrease in the alloy content and the evolution of gas which occurred during the tests make it seem probable that the alloying elements in these layers are combined chiefly with hydrogen. Two possible explanations for the formation of flakes are proposed. The first depends on the assumption of an embrittlement of the basic structure caused by a precipitation of hydrides. The second rests on the breakdown of these precipitated hydrides into hydrogen and the solid element in the compound ; the high internal pressure thus set up, together with the simultaneous embrittlement of the structure due to incomplete decomposition of the precipitated hydrides, is assumed to be responsible for the formation of the flakes.

Microscopic Studies of Ingot Structures. E. D. Enlund. (Jernkontorets Annaler, 1934, vol. 118, pp. 391–438). The author has studied the development of the structure of ingots and its relation to the quality of the steel, and has determined the effect of varying the method of working the charge with respect to segregation and slag inclusions. Two identical charges (carbon 0·80 per cent.) were selected, but one was pushed somewhat harder than the other. Marked segregation phenomena were noted in the slow charge, but this may have been due to the longer tapping time. The shell of the ingot was more rapidly and evenly etched than the core. Hardness tests showed the exterior to be of somewhat better quality, probably on account of the finer structure. By the addition of sulphur, phosphorus and oxygen various characteristic structures were obtained, which, in conjunction with the chemical analyses, made possible the identification of the impurities in the steel.

A Consideration on the Separation of Non-Metallic Inclusions in the Molten Steel by Means of Difference in Densities. M. Fukusima. (Kinzoku No Kenkyu, 1935, vol. 12, Feb., pp. 89–100). The author deals with the applicability of the various formulæ which have been adopted to describe the behaviour of inclusions when rising through the molten metal, and furnishes data derived from a further study of the subject.

Non-Metallic Inclusions in Ferro-Alloys. B. Matuschka. (Iron and Steel Institute, May, 1935, this Journal, p. 213).

The Homogenisation of Ingots of Chromium-Nickel-Tungsten Steel. S. Křiz. (Stahl und Eisen, 1935, vol. 55, Jan. 17, pp. 67–68). After touching on the usual method of homogenising ingots of chromium-nickel-tungsten steel, the author gives a summary of a research carried out by M. W. Pridanzew and B. E. Scheinin (Katschestwennaja Stal, 1934, vol. 2, pp. 43–49), who examined ingots made from one melt each of a case-hardening and a heat-treatable steel of this type prepared in a 10-ton electric furnace, testing them in the condition as-cast, after soft-annealing and

after homogenising in various ways followed by soft-annealing. Their results showed that, whereas the fracture structures corresponding to the various conditions differed characteristically (in the as-cast ingots the fracture, which was fairly flat, ran through the primary grains, the crystallites, which differed in lustre and dendritic arrangement, being arranged in step formation; in the soft-annealed ingots, the fracture was entirely intercrystalline, with the usual appearance of an amorphous coating round each crystallite; in the homogenised and soft-annealed ingots the intercrystalline fracture somewhat resembled that in hot-deformed metal, and was unaffected by the particular mode of homogenisation), neither the working up of the ingots nor the mechanical properties of the resulting forgings were benefited by the process of homogenisation. In the subsequent discussion on the paper objection is taken to the drawing of conclusions from tests on only two melts, however carefully performed, and the divergence of the investigators' results from those of prolonged practical experience is pointed out. The author concludes by remarking that the benefit of homogenisation is particularly noteworthy when the degree of reduction by forging is not very great.

FORGING AND ROLLING-MILL PRACTICE

REHEATING FURNACES.

Steelworks Instals New Soaking Pit and Crane Equipment. L. E. Browne. (Steel, 1935, vol. 96, Apr. 29, pp. 45–46). Particulars are given of the two 4-hole soaking pits at the South Works of the American Steel and Wire Co., Worcester, Mass. They are of the oil-fired recuperative type.

The Removal of Slag from Soaking Pits and Its Application. A. Rotter. (Stahl und Eisen, 1935, vol. 55, Apr. 18, pp. 433–441). The removal of the slag from soaking pits is attended by irregularities and difficulties. The cause lies in the slight difference between the temperature of the furnace and the melting point of the slag, in the need for completely opening the furnace to withdraw the ingots, and in the irregularity of the cold and hot charges ; a further difficulty arises from the care that must be taken of the quality and structure of the ingots charged. The two usual methods of slag removal—through the top, and from the side—which are discussed in detail, can be used with success. The practice adopted is bound up with the type of furnace, and the conditions in regard to regenerative chamber and hearth furnaces and non-regenerative directly-fired furnaces are considered in full. In presenting the operating figures given, attention is drawn to the conditions in basic Bessemer works, where the mode of operation in regard to ingot handling differs essentially from that in open-hearth works. Then follows a comparison of the non-regenerative and the regenerative furnace, showing that the former gives the better operating results in most respects ; even in years of minimum furnace utilisation, such as 1933, when the greatest difficulties were presented by the intermittent charging and the great variation in the quality of the ingots, which included a large proportion of cold ones, the advantages of the non-regenerative furnace with waste-heat utilisation were generally proved. In detail, the regenerative chamber furnace was found to handle cold charges best, and the regenerative hearth furnace with side slag removal offered the least slag difficulties. In conclusion, the new long-hearth pit furnace at Witkowitz is described ; its low cost of building is made apparent by a comparison with an American regenerative chamber furnace.

Heating for Forging. J. B. Nealey. (Heat Treating and Forging, 1934, vol. 20, Oct., pp. 479–481). Particulars are given of the forge furnaces in operation at the plant of the Transue and Williams Co., Alliance, Ohio.

The Time Required for Heating Steel. J. D. Keller. (Heat Treating and Forging, 1934, vol. 20, Oct., pp. 487–490 ; Dec., pp. 586–590 ; 1935, vol. 21, Feb., pp. 63–67 ; Mar., pp. 117–120). The author presents mathematical formulæ and curves for calculating the time required for heating plates or slabs, rounds or cylinders, and square bars (*see* Journ. I. and S.I., 1934, No. I. p. 500).

An Effect of Oxygen and Sulphur on Iron in Scaling. J. H. Whiteley. (Iron and Steel Institute, May, 1935 ; this Journal, p. 181).

Investigations in Rolling-Mill Furnaces on Loss by Burning and Surface Decarburisation. J. Meyer and K. Skroch. (Stahl und Eisen, 1935, vol. 55, Apr. 11, p. 423). Brief details are presented of tests carried out in two furnaces—one fired with pea-coal and the other with a mixture of coke-oven and blast-furnace gas—to determine the extent of the loss by burning and the degree of surface decarburisation of ingots of 0·41 per cent. carbon steel. It is shown that, apart from the effect of the furnace type, the decrease in the carbon content towards the surface and a diminution of the depth of decarburisation are correlated with increasing degree of deformation. The decrease of decarburisation at the surface with increasing deformation demonstrates the influence of the scaling during rolling. The decarburisation was greater and extended deeper into the metal heated in the gas-fired than in the coal-fired furnace ; also the influence of the scaling on the surface carbon content with increasing deformation was less noticeable in the metal from the latter furnace. The influence of the furnace type on the results is also discussed.

The Sensitiveness of Alloy Steels to Burning Phenomena. H. Schrader. (Technische Mitteilungen Krupp, 1934, vol. 2, Dec., pp. 136–142). The author presents a study of the " burning " or surface oxidation of steels, and shows that in order that alloy steels may be heat-treated with safety great care must be given to the conditions under which the metal is heated. Under annealing conditions which would be quite suitable for carbon steels, detrimental penetration of oxides into the surface layers of some steels is to be feared. Nickel, cobalt and molybdenum steels are particularly susceptible to " burning," but additions of copper, silicon, aluminium, chromium and tungsten effect an improvement as compared with carbon steels. In carbon steels the method of manufacture and the carbon content have little or no influence on the development of " burning " phenomena ; varied contents of manganese, vanadium and titanium also have practically no effect.

Recent Investigations on the Loss by Burning in Conveyor-Type and Pusher Furnaces. F. Wesemann. (Stahl und Eisen, 1935, vol. 55, Jan. 10, pp. 33–38). After discussing briefly the

economic loss caused by burning losses in reheating furnaces, means for determining them, and previous investigations, the author reports the results of a co-operative research carried out in Upper Silesia, and discusses the effects of various factors on the losses (heating period, temperature of withdrawal, furnace atmosphere, furnace type, position of the material to be heated in the furnace) and the relations between the dimensions of the material being heated, the heating time and the " surface loss." The tests were made in both conveyor-type and pusher furnaces. The author concludes that the designation of the loss as a " weight " loss and its representation as related to the weight of the ingot, as has usually been done in the past, has no clear-cut meaning. As the conditions determining the loss play their part at the surface of the material, it is better to relate the loss to the surface area, and call it " surface " loss. The " surface " loss is very dependent on the heating time ; the curve relating these functions for a withdrawal temperature of 1,200° is a straight line, and that for a temperature of 1,300° a line curving downwards, both passing through the origin. This applies to ordinary pusher and conveyor-type furnaces, heated with coal, producer gas (clean or dirty) and coal-dust. Heating with hydrogen-rich gases or with a large excess of air—in general, an increase of oxygen and steam in the combustion gases—increases the burning loss. If the material is allowed to lie freely in a batch-type furnace so that it is subjected to higher temperatures throughout, the " surface " loss in relation to the heating time rises, at first very much, then steadily less, and exceeds by far the value for pusher-furnace operation ; this is particularly marked in the temperature range up to 1,200°. The principal results of the research are the different courses of the surface-loss/heating-time curves for different withdrawal temperatures, and their basically different shape when heating the material in a batch-type furnace. It is apparent that the loss is dependent not only on the heating period, withdrawal temperature and furnace atmosphere, but also on the type of furnace.

Scaling and Surface Decarburisation of Steel under the Influence of Various Gases. W. Eilender. (Gas- und Wasserfach, 1934, vol. 77, pp. 757–762, 779–784).

The Regulation of the Development and Distribution of the Heat in Annealing and Heating Furnaces by Means of Subdivided Air Supply. E. Senfter. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Apr., pp. 427–431). Uniformity of temperature is the prime requisite of all annealing and heating furnaces. Its attainment has been sought by the use of muffles and lattice walls, but these, as the author shows, have certain disadvantages. Subdivision of the combustion of the fuel by the use of numerous burners was introduced, but, nevertheless, in the immediate

neighbourhood of the burners it is not always possible to fulfil completely the condition of perfect uniformity of temperature. For this reason the subdivision of the air or of the fuel gas is proposed. In practice, it is the air which is subdivided. The fuel gas is mixed with less than the amount of air required for perfect combustion and the mixture is fed to the burners ; incomplete combustion ensues, but the gases pass on and encounter the rest of the air required for combustion, which issues at high velocity from nozzles suitably placed in the furnace. By this method the flame temperature at the burners can be so controlled that overheating of the material near them cannot occur, and the disadvantages of individual-burner firing are largely avoided. When lighting up a cold furnace or when maintaining low temperatures certain precautions must be observed to maintain combustion of the air-gas mixture. The author discusses the calculation of the subdivision of the air supply according to the conditions required in the furnace.

FORGING, STAMPING, AND DRAWING.

New Heavy Forge at Vickers' Works of the English Steel Corporation, Limited. (Iron and Coal Trades Review, 1935, vol. 130, Feb. 15, pp. 285–289). **The Heavy Forge Department of the English Steel Corporation.** (Engineering, 1935, vol. 139, Feb. 15, pp. 161–164). A complete illustrated description is given of the layout and equipment of this forging plant. The 7,000-ton press is stated to be the largest to be operated by a high-pressure electro-hydraulic pumping set. The main features of the press are as follows : Normal working pressure, $2\frac{1}{2}$ tons per sq. in. ; automatic gear set to limit maximum pressure $2\frac{3}{4}$ tons per sq. in. ; maximum designed pressure of pumps, 3 tons per sq. in. ; normal total forging pressure, approximately 7,000 tons ; single-cylinder forging-ram diameter, 60 in. ; area, 2,827 sq. in. ; stroke, 102 in. Particulars are also included of the press control gear, the pumping set, the reheating furnaces and the electric supply.

15,000-Ton Hydraulic Forging Press. (Engineering, 1935, vol. 139, Feb. 1, pp. 112–115). Illustrated particulars are given of the design and construction of a 15,000-ton forging press of German design, which can accommodate forgings up to nearly 16 ft. in diameter. There are three main rams, the centre and larger one exerting a pressure of 6,000 tons, and the two smaller each exerting a pressure of 4,500 tons. For the return action, eight rams are provided, arranged in pairs, at the sides of the main columns. The maximum stroke of the press is 9 ft. 9 in. and the distance from the lower side of the moving crosshead to the table when the crosshead is in its top position is 23 ft.

New Variable-Blow Hammer Insures Flexibility in Forging Operations. F. J. Vlchek. (Iron Age, 1935, vol. 135, Feb. 7, pp. 22–23). A new type of forging hammer, of American design, is described, that will deliver either light rapid blows or long heavy blows simply by working a foot treadle.

Small Forgings in Iron and Mild Steel. W. R. D. Jones. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 215–220). An account is given of experiments on hand-forged and drop-forged D-links. Links of wrought iron and steel were used; the eyes and rivet holes were either punched or drilled. Macrostructures were examined, hardness contours obtained, and tensile tests carried out. It is concluded that mild steel is superior to wrought iron, and drop-forging is better than hand-forging, whilst rivet and pin holes should be drilled, not punched. The importance of the correct forging temperature and of proper service normalising is emphasised.

Metallurgical Control of Forging Practice. J. W. Jones. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 193–196). The author refers to the necessity for correct temperature control in forging, and the economies to be gained from the use of alloy steel dies. He indicates the methods which may be employed for revealing the macrostructure of forgings.

Weldless Boiler Drums. M. Ulrich. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Apr. 13, pp. 463–467). As the working pressures of boilers were raised, so a time came when the riveted joints, used for so many years, became inadequate. For the further development of boiler construction weldless drums became essential. In this article the author describes and illustrates the processes of forging, welding and weldless rolling now used for the production of these drums.

Wrought Steel Wheels Carefully Processed. M. M. McCall. (Iron Age, 1934, vol. 134, Dec. 13, pp. 12–15; Dec. 20, pp. 18–21). Illustrated particulars are given of the Carnegie process for the production of wrought car wheels for railways. The ingots used are $16\frac{7}{8}$ in. in diameter at the big end and taper down to $15\frac{1}{2}$ in. They are $85\frac{1}{2}$ in. long and have twelve corrugations, each $\frac{3}{8}$-in. deep. The ingots are sliced and broken up into discs which are subjected to two forging operations prior to rolling. After rolling, the wheels are coned and sized. The various stages of production are shown and particulars of the arrangement of the rolling mill are given. The heat treatment of the wheels for toughening the rims and the final machining operations are described.

Alloy Cast Iron Dies for Sheet Metal Working. (Sheet Metal Industries, 1935, vol. 9, Jan., pp. 31–33). Data are presented on the composition and properties of alloy cast irons used for dies in the pressing and drawing of metals.

Recent Developments in the Use of Presses and Press Tools. N. C. Wilson. (Journal of the Institution of Production Engineers, 1935, vol. 15, Apr., pp. 179–198). The author refers to the improvements made in modern coining pres es, and continues by giving an account of the types of machine used in sheet metal work. Drawing and pressing tools are treated, and some of the more interesting operations discussed; certain special attachments are described.

Some Notes on Power Presses for Sheet Metal Working. (Sheet Metal Industries, 1935, vol. 9, Mar., pp. 143–145; May, pp. 293–303). A general discussion of the types of power presses in use and the factors to be considered in the selection of the most suitable press for any particular class of work.

Fisher Body Instals Huge Presses to Make "Turret Top." (Iron Age, 1935, vol. 135, Jan. 17, pp. 15–18). An illustrated account is given of the equipment and methods used at the plant of the Fisher Body Division of the General Motors Corporation for the pressing of motor car roofs. The roofs consist of single sheets of seamless drawn steel extending from the wind shield to a point well below the rear window. In the production of the roofs the sheets pass through four presses.

Elastic Deformation in Pressed Metal. (Sheet Metal Industries, 1935, vol. 9, May, pp. 320–322).

Cold Pressing and Drawing: A Research into Tests for Materials Used in Cold-Pressing Operations, with Special Reference to the Fluid Pressure Cupping Test. H. J. Gough and G. A. Hankins. **Cold Pressing and Drawing—The Metallurgical Aspect.** C. H. Desch. **New Researches on the Drawing of Cylindrical Shells.** G. Sachs. (Institution of Automobile Engineers, Mar. 5, 1935). In the first paper the authors present the results of an examination of some of the mechanical tests often employed for sheet metal, particular attention being given to the investigation and development of the fluid-pressure cupping test devised by Jovignot. The standard Guillery cupping machine has been adapted to carry out the Jovignot test, but the thickness of the materials that can be tested in this machine is limited by the maximum permissible oil pressure, which is about 1 ton per sq. in. In order to use this form of test on thicker materials, an oil-pressure cupping machine having a capacity of 5 tons per sq. in. was designed and constructed at the National Physical Laboratory, and typical autographic diagrams obtained in this machine are shown. In addition to the fluid-pressure cupping tests made on a variety of materials, cupping tests of the more standard types were carried out for comparative purposes in addition to the usual tensile tests, &c. The general conclusion drawn from this study of the complete deformation curves is that, probably, very valuable information, with regard to the suitability

of a metal for cold-pressing operations, can be obtained from a complete load-extension diagram; such diagrams are much more discriminating than the usual tensile test data (yield, ultimate strength, elongation) or the bursting stress and "cupping coefficient" obtained from a cursory fluid-pressure cupping test. Although complete tensile deformation curves (taken in two directions at right angles) may supply the necessary information, it is fair to assume that a stress-deformation curve obtained in a cupping test is even more useful and may be easier to obtain. Further exploration of the fluid-pressure cupping test appears desirable. A bibliography of literature on the subject of cupping tests is appended.

C. H. Desch discusses the requirements of materials for cold-pressing and drawing. The importance of grain size is pointed out and the formation and elimination of stretcher strains are touched upon. Ageing phenomena and surface condition are also dealt with.

G. Sachs presents an account of the behaviour of a material during the drawing of cylindrical shells, and discusses the various factors governing the operating conditions.

The Sheet Metal Department of Vauxhall Motors, Ltd., Luton. (Sheet Metal Industries, 1934, vol. 8, Dec., pp. 705–708). An illustrated account is given of the equipment and methods used at this plant for the deep-drawing and pressing of automobile parts.

The Sheet Metal Department of Briggs Bodies Ltd., Dagenham. (Sheet Metal Industries, 1935, vol. 9, Feb., pp. 91–94). An illustrated account is given of the equipment of these works.

The Deep-Drawing of Sheet Steel. L. B. Hunt. (Newport and District Metallurgical Society, Jan. 12, 1935: Sheet Metal Industries, 1935, vol. 9, Feb., pp. 101–103; Mar., pp. 154–156). The author discusses the equipment used in deep-drawing, the flow of the material in the dies, steel sheets used for deep-drawing, and the phenomenon of stretcher straining.

Influence of the Shape of the Die on the Self-Stresses and Strength Properties of Cold-Drawn Steel Rods. H. Bühler. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Apr., pp. 465–466). In experiments on samples of steels St 37 and St 60, cylindrical dies produced relatively high stresses in the rod. Steep dies produced principally a deformation of the surface; thus, for instance, bright-drawing with a steep die produced a material with very much lower stresses than did the usual type of die; with steep dies the power consumption was generally higher. On account of the bad frictional conditions, the cylindrical die required by far the greatest amount of power. A normal die produced a smooth and unexceptionable surface, whereas that from a cylindrical die was streaky and porous. For a particularly

smooth surface at low drafts, the use of a steep die is recommended. As the steepness of the die increases, the tensile strength and yield point of the rod increase, the latter more rapidly than the former. Any influence of the shape of the die on the elongation and reduction of area could not be observed.

ROLLING-MILL PRACTICE.

The Rolling of Steel. H. Williams. (Journal of the Institution of Production Engineers, 1935, vol. 14, Feb., pp. 49–71). The author discusses in simple language the main principles of the rolling process, and outlines methods for rolling various iron and steel shapes.

Measurement of the Surface Temperature of Rotating Rolls. P. Wintergerst. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Jan. 19, pp. 76–77). A brief description is given of the usual type of contact pyrometer used for measuring the surface temperature of rotating rolls, experiments made to determine the sources of error in it and to correct them if possible are outlined, and a new form of contact pyrometer based on the results obtained is described.

Experiences with Measuring Apparatus, Particularly Dynamic Extensometers, for the Investigation of the Rolling Process. H. Hoff and T. Dahl. (Stahl und Eisen, 1935, vol. 55, May 2, pp. 485–491). Modern apparatus for measuring the speed of rolling, the length of the material after rolling, the power absorbed by the motor and the work lost in the roll bearings, are described, and their advantages over previous appliances are pointed out.

Rolling-Mill Rolls in Cast Steel. Their Manufacture—Their Defects. L. Quincy. (Revue de Métallurgie, Mémoires, 1935, vol. 32, Jan., pp. 1–22 ; Feb., pp. 69–84). The author presents a very complete discussion of the various defects that may form in cast-steel rolls, such as blow-holes and other flaws for which the foundry may be to blame, piping, heterogeneity, both longitudinal and transverse, liquation, segregation, hair lines, planes of segregation, planes of cracks or fissures, and gives consideration to means for their avoidance or minimisation. He shows that, while some of the flaws due to defective technique can be avoided completely, pipe, though it can be reduced very much by keeping the feeder-head filled and by heating it, cannot be suppressed completely, while there is no sure remedy for some of the most serious troubles (hair lines, and cracks), which generally lead to the rejection of the roll.

The Use of Roll Collars and Collared Rolling-Mills. H. Cramer. (Stahl und Eisen, 1935, vol. 55, Feb. 28, pp. 235–239). The

author first discusses the influence of the cost of the roll and of turning it on the cost of cutting new sections, and their dependence on the size of the section in the case of open passes. He describes various methods of turning rolls by means of examples with and without blind passes. He makes a comparison of the costs of turning, and shows that this heavy expense is the cause of the use of collared rolls. He gives examples of various methods of fixing the collars on the rolls (by keys, shrinking-on, pressing on, bolts, &c.), and discusses the advantages and disadvantages of roll collars. He describes the roll form and calibration of the rolls employed by Messrs. Hermann Irle, of Deuz, in their single- and multiple-collared two-high mills to reduce the cost of turning the sections and of the rolls. He concludes with an example of a closed-pass profile.

Composite Rolls. H. Cramer. (Iron and Coal Trades Review, 1935, vol. 130, Apr. 26, p. 693). An abridgment in English of the above paper.

New Device Indicates and Records Loads. (Steel, 1935, vol. 96, Apr. 22, pp. 43–45, 52). The unit is designed for insertion beneath a screwdown. It consists of a cylinder carrying split annular rings to which air-gap transformers are attached. Rolling pressure causes the cylinder to bulge, and the rings to expand ; hence the air-gap widens. The motion is translated into an electrical impulse which is registered by a suitable meter. The application of the device is discussed.

General Principles for the Construction and Design of Roller Bearings. W. Jürgensmeyer. (Stahl und Eisen, 1935, vol. 55, May 23, pp. 557–564 ; May 30, pp. 586–589). The author first deals with the design of bearings, the prevention of misalignment of the rollers, guiding the rollers, the importance of adjustability and of ease of insertion and removal. He next discusses frictional resistance of roller bearings and the components of which it is made up ; numerical values for the friction in the usual types of bearing are given. Both oil and grease can be used as lubricants. The importance of the accuracy of fit of the bearing on its seating is emphasised. Formulæ, due to Stribeck and to Palmgren, for calculating the load-carrying capacity are given ; this is dependent on the number of revolutions and on the life. In view of results recently obtained with test bearings, the maximum permissible loads are not included in the tables, but only relative values of load-carrying capacity calculated by Palmgren's method ; it is assumed that the accuracy of manufacture and the quality of the material is equal to that of the test bearings, the formulæ being based on results obtained with them.

Bearings of Pressed Artificial Resin instead of Metal or Lignum-Vitæ Bearings. F. Kiel. (Stahl und Eisen, 1935, vol. 55, Jan. 31, pp. 105–107). After presenting some data concerning pressed

artificial resin, the author discusses the various fields in which it might find application, particularly in rolling-mill bearings. A comparison of bearings made of this material and of lignum-vitæ is made on the basis of the tonnage rolled and on the cost; the former basis of comparison favours the pressed material, but at the moment the cost is too high, owing to the small number of experimental bearings built, though as more bearings of the same type are built the price will drop. Careful tests on a cold finishing mill for thin sheets demonstrated the decreased power consumption with the pressed resin bearings. The construction of the bearings and their lubrication with water are described.

Synthesis of Artificial-Resin Compressed Material for he Manufacture of Plain Bearings. W. Stodt. (Stahl und Eisen, 1935, vol. 55, Feb. 14, pp. 183–185). The author first deals with the synthesis of the artificial resin used in the manufacture of pressed articles, and then describes the application of this material in the construction of bearings for rolling-mills, pointing out the precautions that must be taken when inserting the bearings. He concludes by indicating in what type of mills such bearings have so far been used.

Selecting Proper Lubricants for Antifriction Bearings. O. L. Maag. (National Association of Lubricating Grease Manufacturers, Oct. 16–17, 1934: Steel, 1934, vol. 95, Dec. 3, pp. 31–32, 52). The author discusses the requirements to be met in the lubrication of antifriction bearings, with special reference to the use of compounded greases. Lubricants for service under heavy pressures are dealt with and several examples cited. The advantages of oil circulation are also enumerated.

Industrial Lubrication and Lubricants. O. L. Maag. (Blast-Furnace and Steel Plant, 1934, vol. 22, Nov., pp. 625–628, 644). The author discusses the development of various types of lubricants to meet the needs of antifriction bearings.

Lubrication as Affected by Physical Properties of Lubricants. R. C. Williams. (Industrial and Engineering Chemistry, 1935, vol. 27, Jan., pp. 64–66). The author has studied lubrication problems in the wire-drawing process. There are at least three conditions which must be satisfied in order to obtain the most efficient lubricant: (1) The lubricant must adhere strongly to at least one of the surfaces—the wire or the die; (2) it must be solid prior to being subjected to the relative shearing of the surfaces to be lubricated; and (3) the lubricant must melt or be transformed to a fairly mobile liquid between the surfaces while shearing takes place. The coefficient of friction with a solid lubricant that meets the conditions outlined above depends largely, it is believed, on the viscosity and thickness of the film of lubricant rather than on the chemical nature of the lubricant or surfaces.

Steel-Plant Lubrication. J. F. Pelly. (Mechanical Engineering, 1935, vol. 57, Jan., pp. 25–30). The author discusses a number of lubrication problems in steel mills. The various oils and greases used in a large steel plant and their particular applications are tabulated. The lubrication and design of roll-neck bearings are discussed and the savings in power effected by the use of bakelite-composition bearings are pointed out. Attention is also drawn to the advantages of automatic lubrication.

Influence of Design on the Effective and/or Economical Operation of Rolling-Mills. T. W. Hand. (Journal of the West of Scotland Iron and Steel Institute, 1934–35, vol. 42, Part 3, pp. 37–44). A review of developments in the design of rolling-mills and auxiliary equipment. Electric driving, shafts and couplings, bearings and lubrication, and facilities for roll changing are discussed. The layout of the continuous mill of the Whitehead Iron and Steel Co., Ltd., and of the plate mill of Colvilles, Ltd., are shown.

Rolling-Mill Practice. E. R. Mort. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 187–192). The main features of a modern blooming mill are ease of control, improved lubrication and bearings, rapid screw-down gear, and heavy-duty mill tables. In America continuous plate-mills are common ; four-high stands are usual, the rolls running in roller bearings. Noteworthy advances have been made in the design of mills for the rolling of strip ; these are of very massive construction. The mechanised three-high roughing mill appears to be displacing the two-high mill.

Single-Pass Two-High Special Mill Train for an Output of 180 Tons per Hour. (Stahl und Eisen, 1935, vol. 55, Mar. 28, pp. 353–356). An illustrated description is given of a single-pass, two-high mill train built by Demag, A.-G., and of its accessories. The material progresses uninterruptedly through seven or nine pairs of rolls, according to the rolling programme, but is never worked simultaneously by two stands ; further, twice during the rolling it is moved sideways. The roll housings are arranged in three lines, so that, although the material runs out freely behind each mill, only a comparatively short shop is required. Particulars of details of the mill housings and of the arrangement of the saws, cooling beds, shears, transporting gear, &c., are given. The output averages 120 tons per hr., but will be increased to about 180 tons when a second cooling bed has been installed.

Continuous Billet Mill. (Stahl und Eisen, 1935, vol. 55, Mar. 7, pp. 280–281). Illustrated particulars are given of a continuous billet mill which has been added to the plant of the Aciéries de Micheville (*see* Journ. I. and S.I., 1934, No. II. p. 582). The mill consists of five housings containing rolls, 410 mm. in diam., and 800 mm. long, all driven together by a 2,400-H.P. a.c. motor.

The rolled product is cut into lengths in a flying shears with an error of only 0·1 per cent. in the length. The cut billets are transferred to the cooling bed by a pusher and skew rollers. The material is rolled from 100 × 80 mm. down to sections measuring 70, 60, 50 and 45 mm. square, and the output of 50 × 50 mm. section amounts to 160 tons per hr.

Guide Box for the Rolling of Rounds. H. Sedlaczek. (Stahl und Eisen, 1935, vol. 55, Apr. 25, pp. 466–467). The author first discusses the manner of rolling round sections, and the twisting of the rod about its own axis ; he describes the possible causes of this twisting and the manner in which they may be recognised and the twisting prevented. He then points out the disadvantages of some of the types of guide boxes in use and concludes with a brief description of a new type which he has invented. In it the oval cheeks are readily and rapidly moved towards or away from each other by the action of a single lever ; the rod is easily entered, and the cheeks then close on it and present it centrally to the pass without possibility of its twisting.

The Rolling of Broad- and Parallel-Flange I-Beams. F. Engel. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Mar. 23, pp. 390–392). After touching on the development of the rolling of broad- and parallel-flange I-beams, the author gives a brief account of the methods of rolling devised by Sack, Grey, Max Meier, the Bethlehem Steel Co., and Puppe.

New 3-High Roughing Mill Unit Designed to roll 1,800 Pairs in 8 Hours. (Steel, 1934, vol. 95, Dec. 17, pp. 24–27). **High-Speed Features New Sheet Roughing Mill.** (Iron Age, 1934, vol. 134, Dec. 20, pp. 22–24, 76). Details are provided of a new 3-high roughing-mill at the plant of the Tata Iron and Steel Co., Jamshedpur, India. The mill forms part of the extension to the sheet mill, and is designed for roughing 12-in. bars in five passes to 15–16 gauge sheet. It is claimed to be the fastest of its kind yet built ; a 16½-lb. bar, measuring 37½ × 12 × 0·396 in., is reduced to a pair of sheets in 16 sec. The rolls are of molybdenum steel ; the middle roll may be removed without stopping the mill. A description of the screwdown gear, tables and operating controls is furnished, in addition to the schedule of passes and a diagram of the layout of the mill.

The Deflection of the Rolls in Plate, Sheet and Strip Mills. J. S. Caswell. (Iron and Steel Institute, May, 1935 ; this Journal, p. 115).

Some Characteristics Concerning the Hot and Cold-Rolling of Flat Stock. J. S. Caswell. (Sheffield Metallurgical Association, 1935, Jan. 22 : Iron and Steel Industry, 1935, vol. 8, Mar., pp. 227–229 ; Apr., pp. 273–274). The author first explains that in rolling flat stock to close limits elastic deformation due to working stresses or misalignment of the rolls is an important

factor, and considers the mill changes which affect the thickness of the stock. He then goes on to examine the modifications in mill design (such as the use of backing rolls) which have been adopted as a means of reducing the roll deflection and the energy required to operate the mill. The questions of roll temperature control and stock tension are also discussed.

Cold-Rolling. L. Weiss. (Zeitschrift für Metallkunde, 1935, vol. 27, Apr., pp. 73–75). The author first reviews, briefly, previous articles on the subject of cold-rolling. He then discusses the pre-calculation of the rolling pressure and its dependence on the friction and the diameter of the rolls. He presents a diagram showing the possible drafts for various roll diameters, different thicknesses on leaving the pass, and various conditions of friction. He also touches on the limitation of the draft imposed by the permissible specific roll pressure.

Design of Rolling-Mills for Cold-Rolling Metals, Ferrous and Non-Ferrous. C. E. Davies. (Iron and Steel Industry, 1935, vol. 8, Apr., pp. 265–271, 274). The practical and theoretical considerations which govern the design of strip mills in particular are considered. Roll deflection, roll bearings, and lubrication are touched on, and the development of backed-up mills receives special attention, together with the advance in design which has thus been made possible. The importance of the coilers, in view of present-day high rolling speeds, is stressed, and the necessity for structural rigidity is emphasised.

Evolution of the 12-high Cold-Rolling Mill. (Iron and Coal Trades Review, 1935, vol. 130, Jan. 25, pp. 165–166). The phenomenon of slip in the rolling of sheets and strip can be reduced by employing rolls of small diameter, and the arrangement of 4-high and 6-high mills is shown. A recent development is the introduction of the Rohn mill which consists of twelve rolls. The working rolls of this mill have a diameter of 1·6 in., the intermediate rolls a diameter of 3·3 in., and the backing-up rolls a diameter of 6·7 in. The barrel length of the rolls is 11·8 in. A mill of this type has been put into service at the plant of Heraeus Vacuumschmelze for the rolling of alloy steels.

Developments in the Iron and Steel Industry During the Year 1934. (Iron and Steel Engineer, 1935, vol. 12, Jan., pp. 29–33). Tables are presented which give information concerning the electrical and mechanical characteristics and the estimated annual capacities of several important sheet and strip mills started up in the United States in 1934.

New Broad Strip Mill of Sheet and Tube Starts Production in Record Time. J. D. Knox. (Steel, 1935, vol. 96, Apr. 29, pp. 42–43, 56). The layout of the new hot strip mill of the Youngstown Sheet and Tube Co., Youngstown, is described and illustrated. The mill is built with two tandem trains of rolls, the roughing

train and the finishing train. The former includes a 2-high scale breaker, a 4-high spreading stand, a squeezer, and three 4-high universal mills with the vertical rolls on the approach side. The finishing mill comprises a 2-high scale breaker and six stands of 4-high rolls. The slab in transit through the roughing mill passes through the scale breaker, where hydraulic sprays at 1,250 lb. pressure remove the scale from the surface of the steel. Throughout the hot-rolling process both sides of the slab or strip may be subjected to the action of the sprays five times.

76-in. Hot Strip Mill, Inland Steel Company, Indiana Harbour, Ind. R. W. Davis. (Iron and Steel Engineer, 1934, vol. 11, Dec., pp. 486–490). The mill is designed to roll slabs from 3 in. to 4½ in. thick down to strip, sheet and plate, of maximum width 74½ in. and minimum gauge 0·076 in. The mill equipment consists of the necessary furnaces and handling gear, together with one spreading stand, three roughing stands and six finishing stands. The roughing and spreading stands are of the four-high universal type, whilst between each finishing stand is a motor-operated looper. Rapid roll changing is a special feature of the mill. All the plant is electrically driven, motor-generator sets being used to provide a suitable supply to the mill. Considerable care is taken to ensure close speed adjustment and regulation of the finishing stand rolls.

New Thin Sheet and Wire Rolling-Mill. (Stahl und Eisen, 1935, vol. 55, Feb. 21, pp. 206–211). An illustrated description is given of the new thin sheet and wire mill put into operation in April, 1934, at a steelworks in Pretoria, South Africa. The roughing, finishing and continuous mills have been so designed and laid out that with a comparatively simple construction—and, therefore, low cost—a comprehensive rolling programme can be adequately dealt with. All the latest improvements in rolling-mill construction have been incorporated : Precision gear boxes and pinion housings, electric rolls, combined Edenborn and Garrett reels with wire-bundle conveyors ; further, the roller cooling bed is actuated automatically by photo-electric cells.

Developments in the Rolling of Sheets and Strip, 1934. S. Badlam. (Iron and Steel Engineer, 1934, vol. 11, Dec., pp. 500–510). The author presents a survey of the latest developments in American sheet-mill practice. Details are provided of broad-strip mills recently installed, and some attention is devoted to cold-strip mills. Other mills put down during the year are briefly described.

The Modern Method of Manufacturing Sheet Steel. E. R. Mort (Iron and Steel Industry, 1934, vol. 8, Dec., pp. 79–84). The author surveys modern American practice in sheet and tinplate production on wide strip mills, and discusses the applicability of the method in the United Kingdom.

Rolling of Metals with Special Reference to the Sheet and Tinplate Industry. J. S. Caswell. (Sheet Metal Industries, 1935, vol. 9, Feb., pp. 75–76). A brief discussion of the deformation of steel in rolling. The effect of smooth and rough roll surfaces is dealt with.

The Variation of Substance in Tinplates. J. S. Caswell. (Proceedings of the South Wales Institute of Engineers, 1935, vol. 50, No. 5, pp. 339–445). Accuracy of gauge and uniformity of thickness or substance are two of the most important qualities required in a tinplate. Particulars of tolerances in respect of gauge and variation of substance are given and an investigation is described covering the variation of substance produced in the rolling of 28 × 28 in. × 108 lb. tinplates, produced under the following first four systems, and 28 × 19 in. × 107 lb. tinplates produced under the last system :—

1.—The five-part system.
2.—The five-part system, but omitting bars and using specially pre-rolled "singles."
3.—The four-part system matching on "singles."
4.—The four-part system matching on "fours."
5.—The Cound-Davies five-part system.

An examination of the whole of the stages in the manufacture of tinplate shows that the attempts to approach accuracy are mainly centred in the hot-rolling processes. The efforts in this direction begin in the steelworks bar-mill, and they are afterwards continued in the tinplate works hot mill. There appears to be some incongruity between this condition and the high degree of accuracy which is required in a finished tinplate. There is no doubt that a high degree of accuracy is obtained in the hot-rolling processes, but it is doubtful whether this is of an order adequate for the desired approach to accuracy of gauge and uniformity of gauge in the finished tinplate. It appears desirable, therefore, that the present controlling influence of the hot-rolling processes should be improved, and certain suggested improvements are considered.

The Manufacture of Tinplate. G. A. V. Russell. (Iron and Coal Trades Review, 1935, vol. 130, Jan. 11, pp. 86–87). The author discusses recent developments in the use of four-high mills for the rolling of wide strip for tinplate and outlines the alterations and revisions necessary to apply this method in a representative British tinplate producing unit.

The Production of Blackplate. J. S. Caswell. (Blast-Furnace and Steel Plant, 1935, vol. 23, Feb., pp. 121–123 ; Mar., pp. 193–196 ; Apr., pp. 253–256). The author discusses in some detail rolling-mill practice for the production of blackplate. Roll deflection, roll sweep, roll face compression, deformation of material, temperature variation of material, and roll face friction are dealt with.

Precision Rolling-Mills. S. M. Weckstein. (Iron and Steel Engineer, 1934, vol. 11, Nov., pp. 427–435). Since precision rolling is a matter of roll setting and pass alignment, the author describes a number of layouts showing devices which have been successfully used to adjust the roll passes in both horizontal and vertical mills. The successful methods of applying tapered roller bearings on roughing, intermediate and finishing mills are described.

Electrical Aids to Precision Rolling of Steel. H. A. Winne. (Iron Age, 1935, vol. 135, Mar. 28, pp. 18–21 ; Apr. 11, pp. 12–15, 66). An account is given of the application of the Selsyn electrical device in the control of rolling-mill operations ; electrical gauges are also described. These instruments may be used for the continuous gauging of cold strip. The author also deals with the application of thermionic valves (including Thyratron and phototube devices). They may be used to maintain constant tension in reeling wire, or as limit switches on mill auxiliary appliances. The phototube (or photo-electric cell) is a light-operated relay ; in conjunction with valve amplifiers it may be employed with all kinds of mill gear, mechanical devices being replaced by a beam of light. The photo-electric cell may also be used as an optical pyrometer.

Direct Rolling of Molten Steel. (Iron and Coal Trades Review, 1934, vol. 129, Nov. 23, p. 812). An English summary of a paper by H. Bleckmann describing his method of rolling molten steel by passing it through water-cooled rolls. The original paper appeared in Stahl und Eisen, 1934, vol. 54, Nov. 15, pp. 1177–1180 (*see* Journ. I. and S.I., 1934, No. II. p. 581).

Direct Rolling. T. W. Lippert. (Iron Age, 1935, vol. 135, Mar. 21, pp. 10–17). An illustrated description is given of machinery and methods for the direct rolling of molten metals. Brass and copper have been rolled successfully, and plants have been put down for the rolling of ferrous materials, including stainless steel. The principle of the method is similar to that described by H. Bleckmann.

Electric Power Equipment for Steel Plants. R. H. Wright. (Electrical Engineering, 1935, vol. 54, May, pp. 481–485). An outline is given of the rapid increase in the use of electric power equipment in American steel plants, and the principal types of apparatus in present-day use are discussed. Power generation and distribution equipment are considered briefly, and the types of motors used in different kinds of main mill drives are outlined. Synchronous motors and d.c. motors are shown to have largely superseded the use of induction motors.

Reversing Drives for Blooming Mills. G. Fox. (Blast-Furnace and Steel Plant, 1934, vol. 22, Oct., pp. 572–576 ; Nov., pp. 629–632 ; Dec., pp. 689–692, 697 ; 1935, vol. 23, Jan., pp. 63–65).

The continuation of a series of articles describing the electric driving of blooming mills, with special reference to American practice. (*See* Journ. I. & S.I., 1934, No. II. p. 586).

The Design of Electric Drives. P. M. Gallo. (Blast-Furnace and Steel Plant, 1935, vol. 23, Mar., pp. 185–187; Apr., pp. 262–263). Data are presented for determining the correct design of electric drives to secure maximum operating economy.

General Purpose Motors for Steel Mill Applications. W. E. Snyder. (Iron and Steel Engineer, 1935, vol. 12, Apr., pp. 214–216).

Stresses and Flow of Material in the Drawing of Tubes. E. Siebel and E. Weber. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1934, vol. 16, No. 20, pp. 217–224: Stahl und Eisen, 1935, vol. 55, Mar. 21, pp. 331–334). The authors present a detailed discussion of the phenomena occurring during the drawing of tubes by various processes, such as the stresses set up, the flow of the material, the energy consumed in deforming the metal and overcoming friction, &c. They show the effect, according to the method of drawing, of introducing variations in the tube thickness, reduction in the draft, and other conditions of drawing.

Manufacture of Large Seamless Steel Tubes by the Tschulenk Forge-Rolling Process. A. J. Herschmann and L. Tschulenk. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 851–854). The Tschulenk mill carries three or four oscillating Pilger rolls worked by hydraulic plungers. The rolls are linked to the carriage which holds the hollow cylindrical work piece, so that the latter has a to-and-fro movement. A mandrel with a short plug passes inside the work piece and is attached to the carriage. Forward and circumferential feed of the work block is provided, and the action is that of forge-rolling. The mill is stated to be suitable for the production of seamless steel tubes of diameter ranging from 20 to 60 in. with lengths up to 60 ft. For wall thicknesses in excess of $\frac{5}{8}$ in. only one pass is required.

Economic Importance of the Replacement of Obsolete Equipment in Steel Mills. D. M. Petty. (American Iron and Steel Institute, May 23, 1935: Iron Age, 1935, vol. 135, May 30, pp. 44–47, 80–83: Steel, 1935, vol. 96, May 27, pp. 45–50, 68). Four reasons for replacing obsolete plant are given; they are: Wear; production of articles which no longer satisfy the consumer: high cost of production with existing units; capacity of existing units insufficient. A formula may be deduced relating the various factors which enter into production costs; the author considers these factors in detail and gives illustrative examples.

The Application of Time-Study to Rolling-Mills and Steel Furnace Plant. P. Holmes. (Journal of the Institution of Production Engineers, 1935, vol. 14, Mar., pp. 141–155).

The Importance of Time Studies in Works Management and Industrial Accountancy. H. Euler. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Jan., pp. 319–324).

Time Studies and Measurements of Steam Quantities for the Determination of the Cost of Energy in a Rolling-Mill. E. Senfter. (Stahl und Eisen, 1934, vol. 54, Nov. 29, pp. 1231–1232).

Recording and Evaluation of Operating Observations on the Material Management in a Steelworks. W. Kalkhof. (Stahl und Eisen, 1935, vol. 55, Jan. 17, pp. 60–66).

Bases of the Calculation of Production Costs and of Profit and Loss. H. Kreis. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Dec., pp. 269–276).

ROLLING-MILL AUXILIARY PLANT.

New Roll Grinding Machines. (Sheet Metal Industries, 1935, vol. 9, Mar., pp. 136–137). Two new types of Churchill roll grinding machines are described and illustrated.

Traversing-Work Type Roll-Grinding Machine. (Engineering, 1935, vol. 139, Feb. 15, p. 181). Illustrated particulars are given of a roll-grinding machine in which the grinding wheel unit is stationary and the work is traversed longitudinally. The machine is capable of grinding rolls of diameters ranging from 3 in. to 24 in., the centres admitting lengths up to 8 ft.

The Use of Abrasive Wheels. (H. M. Stationery Office, 1935, Safety Pamphlet No. 7). The pamphlet deals with : The examination and mounting of abrasive wheels ; the speeds at which they should be run and the proper care necessary when in use ; guards, eye protection, and dust removal ; and maintenance. The need of correct mounting is stressed, and limiting peripheral speeds are suggested. It is pointed out that wheels must be carefully handled, whilst stout, well-fitting guards are essential. The methods of removing dust are examined, and recommendations are made on all the above-mentioned subjects.

Manipulators for Rolling-Mills. L. de Feydeau. (Génie Civil, 1935, vol. 106, Feb. 23, pp. 182–184). A number of types of rolling-mill manipulators are illustrated and described.

The Cold-Straightening of Rails and Sections. A. Flügge. (Stahl und Eisen, 1935, vol. 55, Feb. 14, pp. 177–182). The author first discusses the economics of the straightening of rails and sections in straightening machines, and then gives consideration to technical aspects of the question of the manner in which the straightening is to be carried out. He next describes the latest straightening rolls for dealing with rails and tongued-and-grooved piling. Finally, he gives an account of a recently built ingot, rail and beam rolling-mill and its attached straightening shop, and

draws attention to the suitability of the arrangement of the straightening machines and their adaptability to a very variable production programme.

Conveyor Transportation in Continuous Strip Mills. M. J. Anderson. (Iron Age, 1935, vol. 135, Jan. 17, pp. 27–30, 66). The various types of conveying machinery for the handling of materials in American strip mills are dealt with.

The Bonnot-Lentz Billet-Chipping Machine. (Engineering, 1934, vol. 138, Dec. 21, p. 674). The "billeteer," as it is called, consists of a base carrying rollers upon which the billet may be manipulated and clamped. A travelling carriage holding a revolving cutting tool moves longitudinally over the stationary billet. The carriage is returned and the billet turned over; in this way all four faces may be dealt with. There are six tools in the rotating head which is driven by a 20-H.P. electric motor; it may be moved in any direction. The carriage, the rolls, and the manipulator are also motor-driven. It is claimed that the billet surface produced by this machine is smoother than that by hand-chipping, and that it more effectively removes defects.

Refinements in Control Speed Operation of New Billet Chipping Machine. (Steel, 1934, vol. 95, Dec. 3, pp. 24–26). Illustrated particulars are given of a billet chipping machine developed by the Bonnot Co., Canton, Ohio. The machine can deal with billets of any size up to 14 in. square.

MANUFACTURE OF WIRE.

The Early History of Wire. F. C. Thompson. (Wire Industry, 1935, vol. 2, May, pp. 159–162). The author traces the history of wire and wire-drawing.

Wire-Drawing in Latin Literature from Antiquity up to the the Renaissance. W. Theobald. (Glasers Annalen, 1934, vol. 115, pp. 57–59).

The Feistritz Iron and Wire Works in the Rosental. L. Jahne. (Montanistische Rundschau, 1935, vol. 27, Apr. 1, pp. 1–6). The author gives an account of the history and development of this works, which is situated 22 km. south-west of Klagenfurt, in Carinthia.

A New Wire-Drawing Device for Use in Combination with Cold Headers. (Wire and Wire Products, 1935, vol. 10, Mar., pp. 106–107, 123–124). Illustrated particulars are given of the Ajax-Hogue wire-drawing machine which is operated in combination with a cold-heading machine.

Combined Wire-Drawing and Heading Equipment Used in Bolt Making. F. L. Prentiss. (Iron Age, 1934, vol. 134, Nov. 29, pp. 18–19). The drawing of wire and the manufacture of bolts

in continuous combined operations with a wire-drawing machine attached to a cold-heading machine is a recent development. Particulars are given of the combination units of wire blocks and double-stroke cold-heading machines at the plant of the Wasmer Bolt and Nut Co., Cleveland.

Carbide Dies Contribute to Better Wire-Drawing. J. R. Longwell. (Steel, 1935, vol. 96, Jan. 28, pp. 22–24, 42). A general discussion of the advantages of carbide dies in wire drawing.

Wire Manufacture. The Formation of Shapes. R. Saxton. (Iron and Steel Industry, 1935, vol. 8, Mar., pp. 225–226). The author deals with the drawing of shape wires as distinct from circular sections, and points out that it is usually more economical to cold-roll in the intermediate reducing operation.

New Type of Wire Coil Conveyor for Rolling-Mills. A. Flügge. (Stahl und Eisen, 1935, vol. 55, May 9, pp. 515–519). After mentioning known appliances for the continuous transportation and cooling of the wire coils coming from the reels of a wire mill, the author describes and illustrates a new type of overhead conveyor. By its use a uniform fine structure in the wire is produced, and the apparatus takes up little space in the plant.

Bessemer and Open-Hearth Steel Wire. F. H. Nullmeyer. (Wire Association, Oct. 3, 1934 : Wire and Wire Products, 1934, vol. 9, Dec., pp. 439–444, 458). An account is given of the manufacture of Bessemer and basic open-hearth steel wire at the plant of the Youngstown Sheet and Tube Co.

Stainless Wires. R. Saxton. (Wire Industry, 1935, vol. 2, Jan., pp. 7–9). The steels used are either martensitic (hardenable) or austenitic (non-hardening). In any case, care must be taken in annealing these steels otherwise resistance to reduction results. Cold work impairs the corrosion resistance, and the surface must be restored by polishing ; the internal stresses set up tend to cause corrosion. In de-scaling the stainless rods a double acid pickle is usually required.

Alloy Steels for Wire Drawing. I.—Chrome-Vanadium Wires. R. Saxton. (Wire Industry, 1935, vol. 2, Apr., pp. 125–127). The composition of the wire used is (approximately) : Carbon, 0·3 to 0·5 ; chromium, 1·0 to 1·8 ; vanadium, 0·15 to 0·25 per cent. It is mainly employed for valve springs. The bars received from the mill are pointed, and annealed at 650°–700° C. Heating and cooling should be gradual, but boxes are not required. The rods are then drawn and ground to remove surface defects ; or grinding may be done first. During the subsequent drawing the rod is annealed after every two passes. Finally, the rod is annealed, polished, limed, blued and repolished, and put through the finishing die. Samples are submitted to a corrosion test and examined under the microscope.

The Deformation Conditions in Wire-Drawing. E. Siebel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1934, vol. 16, No. 20, pp. 213–216). The author has investigated the deformation during wire-drawing by dividing longitudinally rods of copper and scratching a network of lines on the inner surfaces; the two halves were then put together again and drawn through a die. His results confirmed those of Taylor and Quinney (Journal of the Institute of Metals, 1932, vol. 49, p. 187), that the subsequent displacements in the outer zone of the drawn material decrease with the number of drafts. The cause of this must be the different degrees of work-hardening in the outer zone and the core; in consequence, contrary to the case of a mechanically-homogeneous material, the outer zone offers greater resistance to the subsequent displacements during the following drafts. The influence of the distortion as revealed by the scribed network of lines on the position of the principal directions of deformation was examined, and the directions of principal deformation in wire-drawing were determined.

FURTHER TREATMENT OF IRON AND STEEL.

PYROMETRY.

Pyrometers in Industry. C. E. Foster. (Wild-Barfield Heat-Treatment Journal, 1934, vol. 1, June, pp. 9–13; Sept., pp. 29–25; Dec., pp. 38–40; 1935, Mar., pp. 50–52). A series of articles, explaining in simple terms the principles of pyrometry, and the development of pyrometers suitable for industrial work.

New Pyrometer for very Hot Gases. E. O. Mattocks. (Metal Progress, 1934, vol. 26, Nov., pp. 30–33). An account is given of a method of measuring the temperatures of hot air-gas mixtures using spectral-line reversal apparatus. By injecting sodium chloride into the air-gas stream monochromatic radiation is secured; the sodium lines are superimposed upon the band spectrum emanating from a tungsten lamp, and matched in intensity by varying the current to the lamp. The latter is calibrated against an optical pyrometer of the filament type.

Methods of Testing Thermocouples and Thermocouple Materials. W. F. Roeser and H. T. Wensel. (Bureau of Standards Journal of Research, 1935, vol. 14, Mar., pp. 247–282). A description is given of the procedure adopted for testing thermocouples and thermocouple materials; details of the methods of calibration are provided, with special reference to the standard couples and fixed points generally employed; calibration by comparison (with a working standard) is also discussed. The methods of interpolating between calibration points are then dealt with, and the necessary cold-junction corrections are tabulated. There follows a discussion of the usefulness of and test procedure adopted for the materials used in both base-metal and platinum thermocouples. The results are summarised in tabular form.

Standard Tables for Chromel-Alumel Thermocouples. W. F. Roeser, A. I. Dahl, and G. J. Gowens. (Bureau of Standards Journal of Research, 1935, vol. 14, Mar., pp. 239–246). An investigation was conducted in order to set up standard tables for chromel-alumel thermocouples. (The chromel contained 90 per cent. of nickel and 10 per cent. of chromium; the alumel contained 95 per cent. of nickel, the remainder being aluminium, silicon and manganese.) Temperature-e.m.f. relations were established for chromel-alumel couples, and checked by determinations using chromel-platinum and alumel-platinum couples; this enabled the chromel and alumel elements to be matched so as to

give a stated thermal e.m.f. at a certain temperature. The thermocouples were calibrated by a platinum resistance thermometer and by a platinum/platinum-rhodium couple. The results are set forth in tables giving temperatures and equivalent thermal e.m.f's.

Chromel and Alumel : Alloys for Thermocouples. W. A. Gatward. (Metal Progress, 1935, vol. 27, Mar., pp. 31–35). The problem of securing uniformity in the alloys used is commented on, and a description of the method of testing thermocouple wire is furnished.

HEAT-TREATMENT EQUIPMENT.

Temperature Regulator for Higher Temperatures. J. Förster and E. Gruner. (Zeitschrift für Electrochemie, 1935, vol. 41, pp. 9–10). Regulation is effected by means of a small subsidiary electric furnace which is connected in series with the main furnace, but the resistance of which is only one-tenth of that of the latter. The temperature in it is therefore only one-tenth of that of the main furnace, so that mercury can be used as the medium for operating a relay controlling the main current.

The Selection and Management of Gas- and Oil-Fired Heat-Treatment Furnaces. G. H. Barker. (Metallurgia, 1935, vol. 11, Apr., pp. 145–146). Some of the factors involved in the operation and selection of gas- and oil-fired furnaces are enumerated.

Recent Developments in Heat-Treatment Furnaces and Auxiliary Equipment. (Metallurgia, 1935, vol. 11, Mar., pp. 135–140). A number of modern furnaces is described, including a vertical cylindrical electric furnace for long forgings, some small continuous electric furnaces, and gas- and oil-fired furnaces. Attention is also given to automatic temperature control.

The Use of Electric Furnaces in Industrial Heat Treatment. A. G. Lobley. (Metallurgia, 1935, vol. 11, Jan., pp. 61–64, 86 ; Mar., pp. 117–120). The author touches on the design of electric heat-treatment furnaces, and proceeds to enumerate their advantages. Batch and continuous furnaces are described, together with methods of temperature control. The usefulness of forced air circulation for low-temperature work is stressed. Furnaces for nitriding, and for continuous wire and strip annealing are also dealt with.

Improved Electric Furnace. (Iron and Coal Trades Review, 1935, vol. 130, May 31, p. 939). An electric furnace for low-temperature heat treatment is described, in which a centrifugal fan is employed to maintain the circulation of hot air through the charge.

Forced Air Circulation. J. E. Oram. (Wild-Barfield Heat Treatment Journal, 1934, vol. 1, Dec., pp. 34–37). The author discusses forced air circulation in electric heat treatment furnaces. The merits and limitations of forced air circulation, and the effect of fan design are considered.

Heat Treatment of Spring Leaves. W. C. Owen. (Metal Progress, 1935, vol. 27, Mar., pp. 51–55, 64). The heat treatment furnace is of a special type ; it is arranged on the conveyor system, and heating is by radiant tubes, above and below the hearth, and through which pass the burning gases. A neutral atmosphere is maintained within the furnace by the use of coal-gas ; special care is taken to prevent the escape of the gas. The spring leaves travel through the furnace and pass to a forming and quenching machine, and so to the tempering furnace ; this, also, is of the conveyor type.

Variety of Furnaces Required in Forming and Heat Treating Steel Springs. J. B. Nealey. (Steel, 1934, vol. 95, Dec. 31, pp. 16–18). Brief particulars are given of the furnaces in operation at the plant of the American Spiral Spring and Manufacturing Co., Pittsburgh, for the heat treatment of springs.

Continuous Controlled-Atmosphere Furnace Used to Harden Automobile Valve and Clutch Springs. F. L. Prentiss. (Iron Age, 1935, vol. 135, Jan. 31, pp. 33–35). An illustrated account is given of the continuous electric furnace in operation at the plant of the Cleveland Wire Spring Co., Cleveland, for the hardening of automobile valve and clutch springs. The furnace is divided into three zones, each of which is independently controlled by recording temperature control instruments. The furnace is equipped with a combustion type of atmosphere controller which produces gas for maintaining the desired atmosphere by the partial consumption of natural gas in combination with air.

Clean Annealing at Motor Wheel Corporation. A. G. Seger. (Heat Treating and Forging, 1935, vol. 21, Jan., pp. 11–12). At an American plant stampings are annealed in atmosphere-controlled furnaces in order to eliminate the subsequent pickling operation. Particulars of the method and furnace used are given.

Bright Normalising and Deoxidising of Sheet and Strip. R. R. LaPelle. (Iron Age, 1935, vol. 135, Feb. 14, pp. 26–29). Brief particulars are given of a roller-hearth type furnace for the bright-normalising and deoxidising of steel sheet and strip. The controlled atmosphere used is produced by treating natural gas or butane. The gases are passed over oxygen-absorbing materials, which remove the small quantity of residual oxygen, and are then cooled to precipitate some of the moisture present.

CEMENTATION AND CASE-HARDENING.

On the Catalytic Decarburisation of Steel. M. Kobayasi. (Kinzoku No Kenkyu, 1935, vol. 12, Feb., pp. 101–119). To test the theory that the velocities of the reactions in the iron-carbon-oxygen system are influenced by catalysts, experiments were carried out with the object of decarburising steel in the presence of the carbonates and chlorides of the alkali and alkali earth metals. The results obtained confirm the theory.

On the Catalysers for the Cementation of Iron. K. Iwasé and W. Ôta. (Kinzoku No Kenkyu, 1934, vol. 11, Sept., pp. 413–421). Experiments were performed to discover suitable catalysts for the cementation process. Salts of the alkali and alkali earth metals were used ; it was found that a mixture of 10 per cent. NaCl and 10 per cent. Na_2CO_3 was the most effective. The influence of temperature was also examined ; with a solid carburiser no free cementite was formed at the surface of the specimen ; this contrasts with the action of gaseous carburisers.

Carburising Practice. J. F. Wyzalck. (Metal Progress, 1935, vol. 27, Feb., pp. 19–23, 64). The author indicates the factors which bear upon the efficiency of the carburising agent and the case-hardening process. The types of furnace used are discussed and the heat treatment to be given to different materials is suggested.

Note on the Carburising of Copper Steels. S. Epstein and C. H. Lorig. (Metals and Alloys, 1935, vol. 6, Apr., pp. 91–92). Structural steels of varying copper content were carburised in the oxidised and as-machined conditions. For steels containing up to 3 per cent. of copper, the carburisation proceeds normally ; above this limit carburisation is uneven. With the oxidised specimens irregularity is experienced with over 1 per cent. of copper ; this may be attributed to a layer of copper which forms below the iron oxide scale and inhibits penetration. If ordinary care is taken to prevent oxidation no trouble should be experienced.

Influence of Alloying Elements on the Behaviour of Steels during Case-Hardening. E. Houdremont and H. Schrader. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Apr., pp. 445–459). The influences of the various alloying elements, in amounts of 3 or 6 per cent., on the surface carbon content, depth of carburisation, hardening depth, structure and sensitiveness to overheating of steels when case-hardened in a mixture of charcoal and barium carbonate under various conditions were determined. All special carbide forming elements (chromium, molybdenum, tungsten, vanadium, titanium) raised the carbon content of the surface, whereas additions of silicon, aluminium, nickel, cobalt and copper, and also phosphorus as an impurity, decreased it. The depth of carburisation was highly dependent on the carburising

conditions. With deep carburisation, most of the elements caused a reduction of the depth. Nickel, cobalt and copper apparently accelerated the diffusion process. With regard to the depth of hardening, as the alloying elements affected the hardenability as well as the depth of penetration, it often happened, as in the case of steels containing manganese, nickel, copper, chromium, molybdenum and tungsten, that although there was a reduction in the depth of penetration the depth of hardening was increased. An additional reduction of the depth of hardening was caused by cobalt, which reduced the hardenability, and by vanadium and titanium, which withdrew some of the hardening carbon by forming stable carbides. In the structure, carbide-forming elements such as chromium, molybdenum, tungsten and titanium, caused an increase in the boundary carbides, while silicon, aluminium and nickel caused the cementite to break down into graphite. In molybdenum and tungsten steels there was a tendency for the formation of an abnormal cementite structure, which was less pronounced in nickel and copper steels. When overheated during cementation, additions of manganese, nickel, cobalt, copper and silicon had a grain-refining effect ; this grain-refinement was particularly marked in the case of carbide-forming elements, such as molybdenum, tungsten, vanadium and titanium, owing to their influence in hindering growth and the nuclear action of carbide nests. On the other hand, steels containing chromium and aluminium were more susceptible to overheating than unalloyed case-hardening steels.

Nitrogen Surface-Hardening of Iron and Iron Alloys. (Metallurgist, 1934, vol. 9, Dec. 28, pp. 188–191). The results of recent research on the nitriding of iron and iron alloys are summarised.

On the Rôle of Al or Cr in the Nitriding Steels. S. Nichigori. (Kinzoku No Kenkyu, 1935, vol. 12, Mar., pp. 148–158). Steels containing aluminium and chromium, singly or together, were nitrided, and the properties of the nitrided layer studied. In addition to hardness tests and microscopic investigation, X-ray analysis was carried out. From the results it was possible to draw inferences concerning the mechanism of nitriding in these steels.

Nitriding Characteristics of Cr-Mo-V Steels. J. Strauss and W. E. Mahin. (Metals and Alloys, 1935, vol. 6, Mar., pp. 59–62). Certain disadvantages accompany the use of aluminium in nitriding steels. Steels containing moderate amounts of chromium, molybdenum and vanadium are free from these defects, whilst the nitrided surface is almost as hard as that yielded by aluminium steels ; it is also tough and ductile. A steel containing 2·65 per cent. of chromium has been found particularly suitable.

Nitrogen-Hardened Cast Iron. A. N. Dobrowidow and Natalie Schubin. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Feb.,

pp. 361–363). For the production of a uniformly hard and even nitrided layer, the cast iron must be free from coarse graphite flakes and ferrite spots; the authors therefore tried to obtain this initial structure by malleablising white iron. It was found that the elements aluminium and chromium, which are essential to the nitrogen-hardening process, must be added in such proportions that the cementite structure of the untreated material would transform into pearlite and temper carbon in a comparatively short annealing period. It was also found necessary to banish any ferrite that might have formed during the anneal by a special heat treatment. The experiments showed that an iron with carbon 2·75, silicon 0·25, aluminium 0·8, and chromium 1 per cent. was suitable; it graphitised on annealing at 1,000° C. for 8 hr., and any ferrite that formed could be converted into sorbite by oil-quenching from 900°. On nitriding, the surface of this iron was perfectly smooth, with a Herbert pendulum hardness of 75–85 units. The toughness of this surface could be increased by small additions of nickel.

Hardening Cylinder Liners. J. Dummelow. (Automobile Engineer, 1935, vol. 25, Jan., pp. 7–9). The author describes the nitriding of cylinder liners. The very high resistance to abrasion obtained by means of this process is shown.

Hardening Cast Iron by Heat Treatment. J. E. Hurst. (Wild-Barfield Heat Treatment Journal, 1934, vol. 1, Dec., pp. 29–33; 1935, Mar., pp. 42–46). The author discusses oil-hardening and tempering, air-hardening cast iron, and quenching and tempering procedure. The nitrogen-hardening of cast iron, and the application of nitricastiron are also dealt with.

The Surface Hardening Treatment Applied to Cast Iron. J. E. Hurst. (Iron and Steel Industry, 1935, vol. 8, May, p. 314). Rods $1\frac{1}{2}$ in. in diam. were cast from a plain cast iron and a nickel-chromium iron, into metal moulds. Short lengths were subjected to the surface-hardening treatment by the Shorter process. Hardness determinations showed a great improvement in surface hardness to have been attained, the depth of hardened case being about $\frac{1}{16}$ in. The original mechanical properties may be restored, if necessary, by a suitable tempering treatment.

Local Surface-Hardening of Crankshafts. H. Voss. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, June 15, pp. 743–749). The local surface-hardening of shafts, particularly crankshafts, can be effected with the aid of the oxy-acetylene blow-pipe. The author has made tests to determine the relation between the rate of heating and the depth of hardening as well as the structure obtained. Other tests, devised in order to observe the reactions taking place within the material, are dealt with in detail. The manner in which the time of heating necessary for hardening to occur varies with the diameter of the

object is shown. Observations on the strength properties and structures of surface-hardened parts provide a picture of the changes in the material resulting from the hardening. In the surface-hardening process, the core material remains unaltered, the hardened layer is adequately thick, and the process is carried out in a short time.

HEAT TREATMENT OF IRON AND STEEL.

Formation of Blistered and Non-Adherent Scale Layers in the Heat Treatment of Steel. M. von Schwarz. (Stahl und Eisen, 1935, vol. 55, Jan. 24, p. 93). Griffiths explained the formation of blisters in scale as being due to forces set up by changes of volume during the formation of the oxide under the action of the surrounding gases (Journ. I. and S.I., 1934, No. II. p. 377). That this explanation does not fit all cases is shown by the example of a box-annealed thin sheet described in this article. A micro-section through the thickness of the sheet revealed a ferrite band, enriched in phosphorus, lying nearer one surface than the other; the nearer surface was blistered and more scaled than the more distant surface, which was free from blisters. It is suggested that the blistering was caused by outbreaks of gas, originating in the slaggy segregated ferrite band, in the inadequately annealed sheet.

Some Thoughts on the Heat Treatment of Steel. R. T. Percival. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 221–222). Some attention is paid to heat-treatment furnaces, particularly in respect of temperature and atmosphere control, and the subject of precipitation hardening is touched on.

Spheroidising Steels. J. A. Duma. (Heat Treating and Forging, 1934, vol. 20, Dec., pp. 583–585). The author explains briefly the spheroidisation of steel and outlines the object of the process.

The Bright Annealing of Steel. (Iron and Steel Industry, 1934, vol. 8, Dec., p. 114). In the process which is described, the steel parts are heated in an annealing pot in the normal way, but on cooling the pot is lowered into a sealed chamber which is flooded with a reducing gas, the excess gas being burnt. On completion of the cooling period the finish is found to be quite bright.

Bright Annealing of Metals in Electric Furnaces. J. Dummelow. (Wire Industry, 1934, vol. 1, Nov., pp. 355–360; Dec., pp. 391–393). In these articles the author surveys the metallurgical and economic factors involved, and considers the Grünewald system in particular. A vertical cylindrical resistance furnace is used, the coils of wire, strip, &c., being placed in a pot which is inserted in the furnace. No special precautions are taken to exclude air on heating, but when the annealing operation

is almost at an end a valve in the furnace cover is closed, and cooling takes place in a partial vacuum. In this way oxidation is prevented. By means of air circulation the hot pots may be made to preheat the cold pots, on a recuperative principle.

Heat Treatment in Controlled Atmospheres Including Gaseous Carburising. C. R. Austin. (Transactions of the American Society of Metals, 1935, vol. 23, Mar., pp. 157–186). A general discussion on the bright annealing of low-carbon steel, stainless steel, silicon steel, copper and brass. Attention is drawn to the more important fundamentals which must be considered, and examples of annealing practice are provided. The theoretical aspects of the annealing of high-carbon steel in neutral and carburising atmospheres are discussed and some practical data are presented on the surface carburisation of low-carbon steels, surface recarburisation of high-carbon steels and the annealing of high-carbon steel in pure dry hydrocarbon gas.

Replying to Six Pertinent Questions on Furnace Atmospheres. W. M. Hepburn. (American Gas Association: Steel, 1935, vol. 96, Mar. 11, pp. 34–36). A discussion of some of the fundamental factors involved in the use of controlled atmospheres in heat-treating operations.

Special Atmospheres in the Heat Treatment and Brazing of Metals. C. L. West. (Iron Age, 1935, vol. 135, May 16, pp. 18–22, 86). In an investigation on the types of furnace gas suitable for the heat treatment and brazing of bright parts it was found that if oxygen was eliminated the gas need not be strongly reducing. The atmosphere is obtained cheaply by the combustion of carbonaceous gases. The application of this method of securing non-oxidising atmospheres is described.

The Heat Treatment of Steels in Controlled Atmospheres. A. G. Robiette. (Iron and Steel Industry, 1934, vol. 8, Dec., pp. 109–114). Heat treatment in controlled atmospheres has much to recommend it. The treatment is usually carried out in an electric furnace. The gas used may be hydrogen, nitrogen or cracked ammonia. This latter is formed by passing ammonia gas over a catalyst at 500°–550° C., when it dissociates into nitrogen and hydrogen; some of the hydrogen may be burnt off by introducing air. Coal-gas and coke-oven gas may be employed, but any sulphur present must be removed. The furnaces are generally of the bell type, but continuous furnaces are being developed; they are especially suitable for strip and similar material.

Box Annealing of Steel Sheets. E. R. Mort. (Iron and Steel Industry, 1935, vol. 8, Mar., pp. 251–255). The design of the covers, and the charging arrangements adopted, are described, and an account is given of the normal box-annealing procedure. The problem of deoxidising the steel sheets during cooling is

examined, and the continuous annealing method is discussed. Some attention is paid to the electric annealing furnaces now available, and the advantages to be derived from their use.

Cold Rolling and Annealing of Razor Blade Steel. (Kalt-Walz-Welt: Sheet Metal Industries, 1934, vol. 8, Dec., p. 691). An outline is given of procedure in the bright-annealing and cold-rolling of razor blade strip.

Heat Treating Steel Castings. J. D. Knox. (Foundry, 1935, vol. 63, Feb., pp. 22–23, 53). Particulars are given of practice at the plant of the Bonney-Floyd Co., Columbus, Ohio, for the heat treatment of steel castings on a large scale. Gas-fired heat-treating furnaces of the car-bottom type are employed and are equipped with automatic temperature control.

Heat Treating Steel Castings Improves Physical Values. J. D. Knox. (Steel, 1934, vol. 95, Dec. 3, pp. 42–45). Reference is made to the great improvement in physical properties to be obtained by heat treating steel castings. Annealed articles are superior to those in the as-cast condition, but quenching and tempering gives much better results—up to 25 per cent. increase in tensile strength, and 100 per cent. improvement in Izod value being obtainable.

An Investigation of Spring Steels. J. H. Andrew and G. T. Richardson. (Iron and Steel Institute, May, 1935; this Journal, p. 129).

Theory of the Heat Treatment of Magnetic Materials. R. M. Bozorth. (Physical Review, 1934, vol. 46, pp. 232–233). The theory of heat-treating magnetic materials, with and without magnetic fields, is discussed with special reference to permalloys.

Selecting the Proper Hardening Treatment. H. W. McQuaid. (Metal Progress, 1935, vol. 27, Mar., pp. 25–30). The author examines the types of heat treatment recommended for such parts as case-hardened carbon and alloy steel gears, and the relations between grain size, heat treatment and mechanical properties.

Hardening of Tool Steels. H. Kallen and K. Gebhard. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Apr. 6, pp. 437–440). The various methods of hardening used for tool steels, their theoretical bases and their application in practice are reviewed. Cold-hardening—that is, hardening by deformation as by hammering, pressing, drawing or rolling—still finds application to-day for certain purposes. Quench-hardening has now been improved upon by two-stage hardening; the piece is plunged first into water and then into oil, the rapid cooling in the first stage suppressing the pearlite transformation and the slow cooling afterwards permitting the martensite crystallisation to take place. Precipitation hardening has now assumed practical importance for steels.

Uniform Hardening of Large Bearing Races. B. Kjerrman and I. Bohm. (Metal Progress, 1934, vol. 26, Dec., pp. 27–31). It was found that soft spots occurred in hardened ball races, and attention was directed to the heat-treatment furnaces. If a reducing atmosphere was used until just before quenching, and excess air then admitted for 5 min. the decarburised skin scaled off; in this way soft spots were eliminated. A reduction in fuel consumption was also effected.

Hardening Power and Tempering of Steels Containing Carbides of Low Solubility, Especially Vanadium Steels. E. Houdremont, H. Bennek, and H. Schrader. (American Institute of Mining and Metallurgical Engineers, 1934, Technical Publication No. 585). The authors have investigated the phenomena which occur during the heat treatment of vanadium steels; reference is also made to tungsten and high-speed alloy steels. They examined a number of vanadium steels of various carbon and vanadium contents, and quenched and tempered them in different ways and at different temperatures. Measurements of the degree of secondary hardening, and of the magnetic saturation were made, in order to account for the phenomena observed. Tests of the mechanical properties were also carried out, and the red-hardness in some cases determined. The inferences drawn by the authors are as follow: On the formation of vanadium carbide, carbon is removed from the matrix; but the carbide, being less soluble in austenite than iron carbide, does not confer great hardening power. The carbide particles inhibit grain growth, hence vanadium steels are not susceptible to overheating. On tempering, the special carbide separates from the α-iron only at higher tempering temperatures, and a sort of precipitation hardening takes place, which gives rise to secondary hardening. In addition, the martensite disintegrates on tempering, thus diminishing the hardness. The net result is the sum of these two effects. The authors' theory is supported by numerous tables, graphs, and micrographs.

Quenching in Water, Brine and Oil. I. N. Zavarine. (Metal Progress, 1935, vol. 27, Apr., pp. 43–46). Details are given of a method of studying the mechanism of quenching by the use of high-speed photography. Small, cylindrical specimens were heated in an electric furnace, and then dropped into a jar containing the quenching medium. In water-quenching a film of steam forms around the specimen; the action then becomes vigorous and scale is torn away. In brine quenching a cloud of salt crystals appears to form. With oil, an envelope of vapour shrouds the specimen, but the action is less violent than with water. The greater quenching velocity obtained with salt solutions may be attributed to the agitation resulting from the production of the cloud of salt crystals.

Formation of Fissures in Steel during Heat Treatment. E. Scheil. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Jan., pp. 309–314). From the position of a fissure in a heat-treated steel specimen, conclusions can be drawn regarding the temperature range in which it commenced to form. As a rule, fissures form first after the last reversal of self-stress in the neighbourhood of the room temperature; this applies also to flakes in steel. Fissuration occurs even at stresses which are considerably below the rupture strength as determined statically; it is more comparable with the dynamic phenomena of alternating fatigue stressing. The fissures commence as microscopically small cracks —microfissures—of which usually only one develops into a macrofissure, but which may frequently also remain invisible. In the special case of flakes, several microfissures grow into macrofissures. Microfissures may conveniently be investigated by a process of repeated hardening with intermediate annealing. Generally, the fissures do not form immediately after cooling, but only after the lapse of some time. Immediate mild tempering reduces the number of microfissures and consequently the damage to the steel.

Combined Effects of Thermal and Transformation Stresses in Quenched Hollow Cylinders of Steel. H. Bühler and E. Scheil. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Nov., pp. 219–222). Hollow cylinders, 50 mm. in external diam. and 350 mm. long, were prepared from very low carbon steels containing from 0 to 17 per cent. of nickel; after quenching, the distribution of the residual stresses was determined. In specimens in which the γ–α transformation took place at high temperatures, small holes bored axially down the bars had no influence on the stress distribution as it occurs in solid cylinders—that is, the outer wall was in compression and the inner was in tension. As the transformation temperature was lowered, a range was passed through in which compressive stresses were found in both the outside and inside zones, with an annular zone of tensile stress in between. At still lower temperatures of martensite transformation, the outer and inner zones were in tension with the intermediate zone in compression. In steels in which the transformation occurred during or after the reversal of the thermal stresses (which may therefore be compared with the usual tool steels) the stress distribution resembled that in solid cylinders. As the size of the bore-hole increased, a stress distribution characteristic of a solid cylinder with preponderating transformation stresses was set up. In this range, particularly high tensile stresses occurred in the wall of the bore-hole as compared with a solid cylinder; these stresses could be reduced by special cooling of the wall of the bore. On further increasing the size of the bore, the stresses in the quenched hollow bodies decreased again.

Influence of Various Elements on the Precipitation Processes in Steel on Tempering. W. Tofaute. (Technische Mitteilungen Krupp, 1934, vol. 2, Dec., pp. 134–135). Reference is made to the work of a number of investigators in this field.

Continuous Air Drawing of Roller Bearings and Similar Parts Using the Air Heater Method. C. F. Mayer. (Industrial Heating, 1935, vol. 11, Apr., pp. 205–207). At the plant of the Timken Roller Bearing Co., roller bearings and similar parts are tempered in gas-fired continuous furnaces by means of heated air at a predetermined temperature and volume. The operating costs are said to be lower than with an electric furnace.

Contribution on the Problem of Temper-Brittleness. W. Bischof. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Jan., pp. 293–299). Tests on chromium, manganese, nickel and chromium-nickel steels, showed that temper-brittleness could be revealed by endurance impact and by bend tests, as well as by the notch brittleness. Physical measurements were either useless or of very limited utility. Investigations on the influence of the quench-hardening temperature, and the duration and temperature of tempering, and also on precipitation phenomena, demonstrated that certain special carbides containing manganese and chromium were the "carriers" of temper-brittleness. Temper-brittleness cannot be explained on the basis of precipitation phenomena; on the other hand, all the experimental results can be uniformly explained on the assumption of the existence of two carbides, one rich in manganese or chromium and the other containing but little of these elements. On rapid cooling, the manganese- or chromium-rich carbide is retained to lower temperatures, at which it breaks down into the poorer carbide, manganese or chromium being separated out. The brittle condition then occurs when the rate of decomposition of the carbides is greater than the rate of solution of the precipitated quantities of chromium or manganese in the ground-mass. Retardation of the rate of solution or of the breakdown provides an explanation of the effects of other alloying elements and of the mode of manufacture.

Heat Treatments and Applications of Nickel-Chromium Steels. M. Tamaki. (Japan Nickel Review, 1935, vol. 3, Apr., pp. 199–206). The properties of representative nickel-chromium steels are tabulated, together with their heat treatments. An explanation of temper-brittleness is advanced (due to Nagasawa) which attributes this defect to carbide precipitation.

The Films Responsible for the Temper Colours on Iron. K. G. Lewis and U. R. Evans. (Chemistry and Industry, 1935, vol. 54, Feb. 8, pp. 128–129). The authors describe an improved method of isolating the oxide-films responsible for the interference tints on metals heated in air. The method, whilst not giving films completely free from secondary product, nevertheless provides

specimens of reasonable size mounted flat on glass or waxed paper.

Heat Treatments of Unalloyed Cast Irons. T. Boissaux. (Revue Technique Luxembourgeoise, 1935, vol. 27, Jan.–Feb., pp. 1–6). The heat treatments intended to improve the properties of a piece of cast iron to suit it for its particular purpose have been dealt with by numerous authors, but their papers, distributed among the literature, view the problem from different aspects. The purpose of the present article is to co-ordinate the various data in order to present a general survey of the present state of the question.

WELDING AND CUTTING.

Symposium on the Welding of Iron and Steel. (Iron and Steel Institute, May, 1935). With the co-operation of fourteen other important Technical Societies, the Iron and Steel Institute organised a Symposium on the Welding of Iron and Steel; the sessions took place on May 2 and 3, 1935. A hundred and fifty papers, covering practically every aspect of the subject were submitted, and they were classified into the following groups :—

GROUP 1.—Present-day Practice and Problems of Welding in the Engineering Industries.

Sub-Group (*a*).—Bridge and structural engineering, pressure vessels (including boilers, pipeline, tubes, tanks and vessels for use at high temperatures and pressures), railway material and shipbuilding.

Sub-Group (*b*).—Aeronautical, automobile, chain, electrical, heavy engineering, and machinery manufacturing industries (including marine engineering), and iron and steel castings and wrought iron.

GROUP 2.—Welding Practice and Technique, including Welding Apparatus.

GROUP 3.—The Metallurgy of Welding.

GROUP 4.—Specification, Inspection, Testing and Safety Aspects of Welding.

Ten Years of German Welding Technique. A. Hilpert and W. Adrian. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Feb. 16, pp. 187–192). A review of the work of the Technical Committee on Welding Technique of the Verein deutscher Ingenieure during the last ten years.

Progress in the Technique of Welding in the First Six Months of 1934. W. Lohmann. (Stahl und Eisen, 1934, vol. 54, Nov. 22, pp. 1212–1216). A review of published information.

Progress in Welding Technique in the Second Half-Year 1934. W. Lohmann and W. Schneider. (Stahl und Eisen, 1935, vol. 55,

May 2, pp. 495–498 ; May 9, pp. 521–522). A review of articles on welding grouped under the following headings : (1) Influence of the materials ; (2) operating methods ; (3) testing methods ; (4) properties of the weld ; and (5) behaviour in operation.

Recent Progress in Autogenous Welding. R. Granjon. (Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1935, vol. 134, Mar., pp. 187–203). A general review of recent progress in autogenous welding and oxy-cutting, and their applications.

Methods of Autogenous Welding. Weldability of Metals and Alloys. D. Séférian. (Revue de l'Industrie Minérale, Mémoires, 1935, No. 341, Mar. 1, pp. 100–112). After very brief mention of the present-day methods of welding, the author discusses the weldability of metals and alloys and the factors which influence this property, such as physical and chemical properties, and their modification during welding, &c. He then discusses the question of establishing a numerical criterion of weldability :

$$S = C \times H$$

where S = the weldability,
C = the continuity or compactness of the welded assembly,
and H = the uniformity or homogeneity of the mechanical properties.

The assessment of numerical values for the factors C and H is considered. In conclusion, the author discusses the weldability of a few steels, cast iron, and non-ferrous metals.

Oxy-Acetylene Welding and Cutting in Metal Working. W. S. Walker. (Iron and Steel Engineer, 1934, vol. 11, Dec., pp. 479–484). This paper constitutes a review of some applications of oxy-acetylene welding and cutting to problems in fabrication. Attention is paid to the welding of pipes, and light tubular members for aircraft construction. The usefulness of the bronze-welding process is pointed out, and some examples of the method of building-up by bronze-surfacing are given. The welding of copper alloys, and of stainless steel alloys is briefly mentioned, but considerable attention is given to the hard-facing process. The softer base metal is brought to a sweating heat, and the weld-metal is melted and deposited in a thin layer upon it. In this way alloy steels, non-ferrous alloys, and sintered carbides may be united to softer materials. Numerous examples are cited. Space is also devoted to the operations of flame-cutting and flame-machining. The latter may be applied to planing, milling, turning, drilling and boring processes.

Thermit Welding. J. B. Tinnon. (Iron and Steel Engineer, 1935, vol. 12, pp. 104–109). The author discusses the economic importance and inherent advantages of the thermit welding process for the repair and maintenance of steel mill equipment.

Control of Transients in Welding Generators. F. B. Hornby. (Electrical Engineering, 1934, vol. 53, Dec., pp. 1598–1602). The fundamentals of d.c. arc welding generators are reviewed, and the effect of transient currents and voltages upon performance are described.

Better Welding Rod Means Better Welding Joints. J. H. Critchett. (Metal Progress, 1935, vol. 27, Jan., pp. 27–30). The process of welding may be regarded as a steel melting operation in miniature. If an attempt is made to produce a low-carbon metal blow-holes are likely to result unless suitable slag-forming elements (silicon and manganese) are added. These remove the scale on the parts to be welded, and promote soundness. If a carburising flame is used still better results may be obtained.

Coatings for Welding Wires. E. Rossow. (Zeitschrift des Vereines deutscher Ingenieure, 1934, vol. 78, Nov. 17, pp. 1358–1359). The losses of elements from welding metal during the process of welding are first touched on, after which the production of the electrode coating and the alloys of iron or other metals which may be incorporated in it are mentioned briefly.

Direct- or Alternating-Current Arc Welding. A. Waclawik. (Zeitschrift des Oesterreichischen Ingenieur und Architekten-Vereines, 1935, vol. 87, Jan. 25, pp. 23–26). The author describes the electrical phenomena occurring in the arc during arc welding by means of direct and alternating current and their effect on the welding process; he also discusses the merits and disadvantages of coatings on electrodes. For welding with a.c., coated electrodes are necessary; for overhead welding d.c. is preferable, owing to the directional properties of the unidirectional current flow.

Important Aspects of Metallic-Arc Welding. W. L. McIvor. (Welding Industry, 1935, vol. 2, Dec., pp. 353–355, 357). The subjects of design, supervision, procedure, control, current regulation, layout and field welding are briefly treated in this article.

Automatic A.C. Arc Welding on Class I. Pressure Vessels. A. O. Tilton. (American Welding Society: Steel, 1935, vol. 96, Feb. 18, pp. 30–33, 64). The author discusses some fundamental considerations in alternating current arc welding and describes equipment and procedure for arc welding pressure vessels, using alternating current.

High-Pressure Boilers Equipped with Fusion Welded Drums. (Welding Industry, 1935, vol. 3, June, pp. 177–178). Particulars are given of a boiler which is said to be the first plant to operate in Great Britain with drums of all-welded construction. The drums are designed for a pressure of 450 lb. per sq. in. Both longitudinal and circumferential joints are of the butt type; the drums were stress-relieved after welding and destructive

and non-destructive tests were carried out. The anticipated performance has been fully realised.

Arc Welding Chromium Steel and Iron. J. C. Hodge. (Metal Progress, 1935, vol. 27, Apr., pp. 33–38). The author briefly refers to the electrodes used, and considers the chemistry of the welding process. He discusses the behaviour of steels containing 4–6 per cent., 12–16 per cent., and 26–30 per cent. of chromium, and stresses the importance of suitable heat treatment and proper methods of testing.

Welded Chemical Equipment from Special Metals. E. P. Poste. (Industrial and Engineering Chemistry, 1935, vol. 27, Feb., pp. 128–134). Developments in the fusion welding of pressure vessels for chemical equipment are discussed. The use of stainless steel is dealt with and particulars are included of the A.S.T.M. tentative standards for the welding of the austenitic chromium-nickel steels to meet severe service conditions. The use of clad steels and non-ferrous alloys is also noted and the various control tests for welded pressure vessels are outlined.

The Arc Welding of Cast Iron. A. F. Davis. (Journal of the American Welding Society, 1935, vol. 14, Apr., pp. 29–32). It is recommended that when welding cast iron the weld metal be deposited in short lengths, or in a curved line, in order to reduce contraction stresses ; peening may also be adopted. The use of non-ferrous electrodes favours ease of machining ; cast-iron rods, on the other hand, are not very satisfactory. Welds in cast iron may be strengthened by studding.

The Practical Side of Electric Resistance Welding. H. S. Jeffs. (Institution of Welding Engineers, 1935, Jan. 9 : Welding Industry, 1935, vol. 3, Feb., pp. 23–29). In this paper the author summarises the main factors in the technique of spot, seam, butt and flash welding.

Recent Developments in Resistance Welding Machines. (Welding Industry, 1934, vol. 2, Nov., pp. 313–315 ; Dec., pp. 347–349). A series of articles describing various types of resistance welding machines.

Resistance Welding Methods in the Sheet Metal Industry. L. B. Hunt and C. F. Davidson. (Sheet Metal Industries, 1935, vol. 9, Jan., pp. 47–50 ; Feb., pp. 111–114). The authors deal with the principles of resistance welding and show the structure of the welds produced. The types of machines used in spot welding are illustrated and a number of aspects of spot welding practice are discussed.

The Development of Welded Plate Girders. H. Gottfeldt. (Welding Industry, 1935, vol. 2, Jan., pp. 361–364). It is pointed out that welded plate girders were initially designed on the same lines as riveted girders, but that there are good reasons for modifying the design to suit the new method of construction. The

adoption of special rolled sections which enable butt-welds to be employed is one such modification. The uses and advantages of these profiles are indicated.

Mass Production and Projection Spot Welding. P. A. Schmatz. (Elektroschweissung, 1934, vol. 5, pp. 204–210: Stahl und Eisen, 1935, vol. 55, Mar. 28, pp. 357–358). A description is given of the "projection" method of spot welding; its purpose is to speed up still further the rate of spot welding, and is applied to the joining together of pressed parts or articles. In pressing the parts to shape them before welding, small projections are raised on the surfaces. The electrodes of the welding machine are provided with studs which register exactly with the depressions at the back of the projections. During the actual process of welding each projection carries welding current (away from them the metal surfaces are not in contact), and consequently by a single operation of the machine a large number of spot welds are made simultaneously. The author discusses the economy of time and costs made possible by this process.

The Process of Electric Spot Welding. Its Application to the Rustless Steels and Light Alloys. G. Mandran. (Aciers Spéciaux, 1934, vol. 9, Dec., pp. 636–680). In the first part the author explains the principles of the process of spot welding, describes machines of various types for carrying it out, and indicates its principal applications. In the second part he deals in detail with the spot welding of 18/8 chromium-nickel steel and gives results of a micrographic examination of such a weld, while the third part relates to the spot welding of aluminium and light alloys.

The Welding of Stainless and Corrosion-Resistant Steels. K. L. Nielson. (Welding Industry, 1935, vol. 2, Jan., pp. 365–370; vol. 3, Feb., pp. 15–17). The author describes the composition and properties of representative stainless steels of the chromium and nickel-chromium types. The problem of weld decay is referred to and the procedure to be adopted in the welding of stainless steel is discussed.

The Welding of Heat-Resistant Alloy Steels. H. Schottky. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Jan. 12, pp. 41–46). After touching on the properties of heat-resistance and of high mechanical strength at raised temperatures, and the effects on them of the addition of alloying elements to steel, the author discusses the welding of such alloy steels and the testing of the quality of the welds produced. He then gives examples of applications in boiler, turbine and furnace practice, and concludes with notes on welding in the chemical industry, particularly in chemical high-pressure technique, and on the attack by hot high-pressure hydrogen on alloy steels and welds made in them.

Machine Design to Suit Welded Construction. A. Thum. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, June 1, pp. 690–692). In the production of a welded part, not only must care be taken in regard to the correct choice of welding method and material, but also attention must be given to such matters as welding stresses, deformation, and correct shape to allow of a smooth flow of the lines of stress. The author gives a number of simple examples to illustrate the various effects which must be given consideration in the design of welded parts.

The Mechanism of Chemical Reactions in Weld Metals. J. H. Paterson. (Institution of Welding Engineers, 1935, Apr. 24: Welding Industry, 1935, vol. 3, May, pp. 152–154). It is pointed out that in order to obtain comparative results from welding tests, standard conditions should be observed; in particular, a standard electrode is desirable. The author gives the composition of such an electrode. He then goes on to discuss the incidence of nitrogen in weld-metal and draws an analogy between carbon-arc welding and metallic-arc welding. In the case of the former, carbon is found to condense in front of the weld crater, whilst the crater metal is found to be rich in carbon, as determined by hardness tests. Similarly, bare electrodes in metallic-arc welding produce a brown deposit containing up to 1·15 per cent. of nitrogen; local hardening of the crater metal is again observed. If a small quantity of wood flour is added to the standard coating a gas envelope is produced during welding, and this largely inhibits nitrogen absorption—a fact which is borne out by analysis and by hardness tests.

Nitrogen in Metallic Arc Weld Metal. J. W. Miller. (Iron and Steel Engineer, 1934, vol. 11, Nov., pp. 450–462). Nitrogen in weld metal deposited by the metallic-arc process might be diminished by: (1) Increasing the carbon content of the electrode; (2) increasing the amperage; (3) decreasing the arc length; (4) increasing the diameter of the electrode; (5) decreasing the nitrogen content of the atmosphere; (6) using heavily coated electrodes. It was found that nitrides might precipitate at the grain boundary or within the grain itself and might also cause widened grain boundaries. The needles present in arc-weld metal are probably the gamma primary phase of the iron-nitrogen system and correspond to the compound Fe_4N. The colourless, structureless areas found in arc-weld metal are probably ferrite areas which are rich in iron nitride that has not had sufficient time to segregate in the form of needles. The main oxide present in weld metal is the magnetic oxide of iron. The author is of the opinion that carbon monoxide and hydrogen, with perhaps the assistance of hydrocarbons, are responsible for the blowholes occurring in weld metal deposited by the metallic arc. No difference was found in the welds produced by annealed and hard-

drawn electrodes. It was found that conditions which lead to the absorption of nitrogen are conditions which lead to the burning out of carbon and to contamination by oxygen. When straight polarity is used, the nitrogen is absorbed at the tip of the welding electrode. When reversed polarity is used, some nitrogen is absorbed at the tip of the welding electrode, some is absorbed by iron when passing through the arc, and some more is absorbed by the metal in the crater of the arc. The carbon is eliminated at the time when, and under the conditions under which nitrogen is absorbed. Evidence was found that the nitrogen, in an air atmosphere, is probably fixed as nitric oxide in the cooler part of the arc, and this is probably split up into active atomic nitrogen and oxygen, both of which may react with the metal. At the elevated temperatures of arc welding the solubility of nitrogen in iron decreases with an increase of temperature. Nitrogen alone will not account for all of the inferior properties found in some metallic-arc weld metal, and other factors play an important part in controlling the physical properties.

The Absorption of Nitrogen by the Fusion of Iron in the Arc and the Iron-Nitrogen Diagram. A. Portevin and D. Séférian. (Académie des Sciences, Dec. 26, 1934: Génie Civil, 1935, vol. 106, Jan. 19, p. 67). The authors first discuss the absorption of nitrogen by iron when the metal is melted in the electric arc, and the influence of various factors on it. Under the most favourable conditions for absorption (bare-wire melting with a long arc) the nitrogen content amounts to 0·18–0·20 per cent.; by the use of atomic nitrogen, however, large amounts of nitrides with 0·25–0·40 per cent. of nitrogen can be formed. The results of micrographic examination of specimens nitrided in this way did not agree with Fry's iron-nitrogen diagram, so the authors have made a fresh study of the subject, and present a new diagram based on dilatometric tests on the specimens.

Contribution to the Study of the Mechanical Properties of Electric Spot Welds. E. J. L. Dussourd. (Aciers Spéciaux, 1934, vol. 9, Nov., pp. 612–626: Bulletin de la Société des Ingénieurs Soudeurs, 1934, vol. 5, Aug.–Sept., pp. 1391–1419: Revue de Métallurgie, Mémoires, 1935, vol. 32, Apr., pp. 171–181; May, pp. 210–214). The author presents the results of the examination of the shear strength and hardness and the macro- and micro-structural characteristics of spot welds made between various steels and under different conditions. In Series I., the effects of variations in the electrode pressure, the duration of welding, the amount of electrical energy consumed and the manner of cooling (whether free, or under pressure) on the properties of the welds between mild steel sheets 5 mm. thick were investigated; in Series II. the mild-steel sheets were only 2·5 mm. thick, and the electrode section and welding current were varied; the third

series of tests was made on a medium-hard steel and a chromium-molybdenum steel, and the influence of reheating was also examined. The author concludes that the weld is made by actual fusion, and the mechanical strength of the spot becomes considerable only when this has happened. In low-carbon steel welds a small cavity forms near the centre in the upper part of the assembly; it is a function of a number of variables, notably the volume of the spot and the thickness of the sheets. Under very good conditions this cavity is less than 1 mm. in diam. for a spot 11 mm. in diam. between sheets 5 mm. thick. With very thick sheets it might be difficult to discover the cavity, and it might be concluded that none was present. Under bad welding conditions an arc may be formed during the bringing together of the sheets; the cavity is then replaced by a crater with oxidised walls. Increasing the electrode pressure diminishes the electrical resistance of the joint and hence the Joule effect, and so must be compensated for by increasing the duration or the intensity of the welding current; the pressure holds the molten metal between the two sheets, and also, through the medium of the plastic joint, balances the counter-pressure due to the dilatation of the melted zone. Maintenance of the pressure during cooling raises the shear strength slightly, (*a*) by maintaining metallic contact during the contraction, and (*b*) by increasing the rate of cooling. In medium-carbon steels, however, increasing the rate of cooling makes the quenching too rapid, and consequently the shear strength is decreased; in this case, reheating is necessary to improve the shear strength. The chromium-molybdenum steel gave better shear strength values than the ordinary medium-carbon steel for similar tensile strengths.

Micro-Mechanical Study of Welds. A. Portevin and P. Chevenard. (Académie des Sciences, Jan. 21, 1935: Génie Civil, 1935, vol. 106, Feb. 2, pp. 118–119). Some results of mechanical tests made on welds by means of a "micro-machine" in which specimens a few centimetres long and about 1·5 mm. in diam. are used, are recorded.

Welding of Structural Steels with Various Electrodes. F. W. Lohmann. (Mitteilungen aus dem Forschungs-Institut der Vereinigten Stahlwerke, Dortmund, 1934, vol. 3, No. 10). The author presents the results of mechanical and other tests on welds in structural steels made with various bare, cored and coated electrodes. Analysis of the wire and weld demonstrated the loss of all the principal elements (carbon, silicon, manganese) except copper, and the pick-up of nitrogen, during welding with bare and coated wires; only by using very heavily coated wires was the loss of silicon and manganese prevented. Annealing the welds for one hour at 920° reduced the ultimate strength and raised the yield point. Hot tensile tests revealed a maximum tensile strength

at 200°–300°, followed by a sharp drop ; this corresponded to the behaviour of the basis metal. Notch impact tests confirmed the bad effect of nitrogen absorption during welding with bare or cored electrodes; from a minimum value at −80° the notch toughness rose to a maximum at 50°–100° and then fell off somewhat ; after artificial ageing the decrease was considerable. Coated-wire welds gave much better unnotched impact tests than did those made with bare wires. Chromium-copper-wire welds were markedly superior in the endurance impact test ; the benefit of coating these electrodes was not so notable.

The Prevention of Weld Decay. E. C. Rollason. (Metallurgia, 1935, vol. 11, Apr., pp. 159–161). The author discusses the problem of weld decay and methods of revealing this defect. He then considers the steps which may be taken to effect a cure ; these are: Suitable heat treatment, reduction of carbon content, the addition of ferrite forming elements, and the production of other carbides, such as titanium carbide.

Metallurgical Data on Fusion Weld Joints. A. J. Moses. (Journal of the American Welding Society, 1935, vol. 14, Apr., pp. 5–19). The author first discusses the conditions necessary to secure adequate corrosion resistance in welded joints, and goes on to examine the quality of welds made with bare and covered electrodes. The problem of stress-relieving is dealt with, with special reference to the behaviour of bare-wire and covered-electrode welds.

Metallurgical Effects Produced in Steel by Fusion Welding. A. B. Kinzel. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 597). The author has investigated the structures and properties of the heat-affected zones adjacent to the weld metal produced in oxy-acetylene welding. The heat of welding produces no noteworthy metallographic effect except in the zone immediately adjacent to the scarf. In this zone, the ductility is reduced, but the tensile strength is increased. If desired, this zone can be completely eliminated by local normalising. The minimum tensile strength in a welded joint exists in the zone subjected to the maximum subcritical temperature. This zone is not necessarily effective in reducing the strength of the joint as a whole. The high ductility of this zone, combined with the small decrease in tensile strength, permits its engineering use at the same fibre stress as that of the plate proper. This zone can be eliminated by general normalising. Commercial plate used for welding purposes is generally susceptible to strain-age brittleness. This may be produced by cold-working the plate before welding, or by internal stress due to the combination of restraint and steep temperature gradients in the welding operation. This can be completely eliminated by general stress-relieving. Steep temperature gradients may do permanent

damage to the welded steel. The problem does not exist for procedure-controlled oxy-acetylene welding, as such steep temperature gradients are never produced. In some other types of welding, the deleterious effect can be avoided to some extent by proper design.

The Effect of Welding Variables on the Physical Properties of Electric Arc Weld Metals. R. R. Blackwood. (Journal of the Institution of Engineers, Australia, 1934, vol. 6, Nov., pp. 421–443). The author outlines the results of a study of the effect of electrode gauge, size of run, welding current and plate thickness on the physical properties of deposited arc weld metal. The effects of these variables on the Brinell hardness, yield point, ultimate tensile strength, elongation, reduction of area, and Izod impact values are considered.

Recent Developments Regarding Welded Joints and the Effects of Fatigue. O. Bondy. (Institution of Welding Engineers, 1935, Mar. 13: Welding Industry, 1935, vol. 3, Mar., pp. 60–64). Lack of knowledge concerning the behaviour of welded joints subjected to fatigue is responsible for a certain disinclination to adopt welding. This can only be remedied by extensive investigation. The types of fatigue stress are: Alternating, pulsating, and superimposed pulsating; the effects of each of these must be considered. For testing small specimens the machines at present available are suitable; for built-up structures a swinging tester may be used, in which vibration is induced by the rotation of two eccentric masses, of which the horizontal components cancel out. With regard to fatigue and the practice of welding, much depends on care in design.

Fatigue Strength of Welds. O. Graf. (Zeitschrift des Vereines deutscher Ingenieure, 1934, vol. 78, Dec. 8, pp. 1423–1427). On the basis of a large number of tests, the author discusses the influence of the external and internal conditions of welds, of the form of the welded joint, and of the welding stresses on the fatigue strength of the welded joint; he concludes by discussing the choice of the permissible load on the welded joint as affected by the external and internal condition of the weld and the form of the joint.

Contribution on the Stresses in Welds. H. Bühler and W. Lohmann. (Elektroschweissung, 1934, vol. 5, pp. 141–145, 165–170, 221–229: Stahl und Eisen, 1935, vol. 55, Feb. 28, pp. 240–242). In view of the use of higher boiler pressures, the problem of the welding-on of patches is becoming of increasing importance. For this reason the authors have made tests to determine the self-stresses which may exist in welds and particularly in those by which a repair is attached to the main part. The stresses were measured by the "boring-out process," the circular discs used being regarded as extremely short cylinders.

Patches, 150 mm. in diam., were welded into annular discs, 250 and 500 mm. in diam. and 20 mm. thick; the magnitude and distribution of the stresses were determined by measuring the change of diameter as the centre was bored out in steps. The results obtained are described; the welds in the larger discs contained higher stresses and revealed the danger of crack formation. Attempts were therefore made to devise a means of reducing these stresses. To determine whether the residual stresses were greater in electric welds or in gas welds, circular grooves were turned in discs and filled up again by welding; the stresses were then investigated as before. The residual stresses were markedly dependent on the size of the welded piece; for small-size discs the stresses in gas welds were much below those in electric welds, but for a larger size the gas-weld stresses overtook and slightly exceeded those in the electric welds; for still larger discs the stresses all decreased again, those in electric-welds rather more rapidly than those in gas welds. The authors conclude that repair welds can be made on mild-steel vessels without difficulty or defects if attention is paid to the basic principles of welding. With increasing strength, the danger of cracking arises when coated electrodes are used; this cannot be entirely avoided, but may be minimised by laying several runs of metal simultaneously or one immediately after another. The use of thick electrodes is also an advantage.

The Stress Distribution in a Welded Joint Subjected to Bending. K. Jezek. (Zeitschrift des Oesterreichischen Ingenieur und Architekten Vereines, 1934, vol. 86, Nov. 30, pp. 276–278). The stresses developed in the basis and the weld metal of a joint, consisting of two long and narrow plates joined at the longer sides by a butt strip welded along its edges, when the whole is subjected to bending in the plane of the plate, are calculated.

Relations Between X-Ray Radiograph and Strength Properties, Determined in Welded Joints. K. Wallmann. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Dec., pp. 243–247). Investigations on welds in 6-mm. and 10-mm. thick steel plates revealed that weld defects, particularly those of two-dimensional form, might remain unobserved in the radiograph if they were unsuitably orientated to the direction of irradiation; bonding defects, however, were always found. On the other hand, three-dimensional defects often led to differences of darkening on the radiograph which did not correspond to their importance in regard to the usability of the material. There is not always a clear connection between the radiographs and the strength properties of the welds examined. Thus, the values obtained in the folding and in the notch tests did not agree with the number and distribution of the defects revealed by X-rays, while in the tensile test with steadily increasing and with alternating loads the results

corresponded to a certain extent to the conclusions drawn from the radiographs. The investigations show that radiography can in many cases give useful information regarding the mechanical behaviour of a material, but that for a final valuation of X-ray testing much still remains to be learned.

Detection of Weld Defects in Radiographs and Their Influence on the Mechanical Properties. W. Tofaute. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Jan., pp. 303–306). In order to elucidate the relation between radiographs and the mechanical properties of welds with intentionally introduced coarse defects, investigations were carried out on arc welds made in mild-steel plates. The elongation, notch toughness and bending angle were decreased most by pores in the weld, while the tensile strength diminished only about half as much, as compared with the elongation. The yield point could not be used to judge the quality of the welds, because the tests indicated the yield point of the parent metal and not that of the weld metal. A prediction of the notch toughness from the radiograph was possible only when the impact resistance of a perfect weld was sufficiently high—for instance, not under 8 kg.-m. per sq. cm. An estimate of the bending angle likewise failed when defects occurred at the root of the weld, that is, in the neighbourhood of the neutral plane. Regarding the various types of defect, it was found that bonding defects at the root or at the side had the greatest effect on the quality of the welds, owing to the formation of sharp notches, whereas collections of pores decreased the mechanical properties only about half as much as did bonding defects.

Radiology in the Welding Art. V. E. Pullin. (Engineer, 1935, vol. 159, Apr. 19, pp. 402–405). The application of X-rays to weld examination proceeds slowly in the United Kingdom, but is common practice in America and on the Continent. The expense of using X-ray plant is off-set by the improvement in the reliability of welds ; interpretation is not difficult and modern units are quite safe to use. X-rays cannot be readily applied to the examination of lap-welds, but for butt-welds the procedure is highly successful. Flaws such as lack of penetration, inclusions, gas cavities, may easily be detected. Moreover, by the use of X-ray spectrum analysis information about the grain size and lattice distortion may be gained. For ordinary weld investigation, the use of a reference frame is an aid to the proper interpretation of radiographs. X-ray inspection may be considered to fulfil a unique function in the testing of welds.

The Brazing of Iron and Non-Ferrous Castings and its Importance in the Foundry. E. Becker. (Giesserei, 1935, vol. 22, Apr. 26, pp. 195–198).

The Penetration of Steel by Soft Solder and Other Molten Metals at Temperatures up to 400° C. L. J. C. van Ewijk. (Insti-

tute of Metals, Mar. 6–7, 1935). Investigation of the failure of a nickel-chromium steel axle tube of an aeroplane showed that the material had been weakened by intercrystalline cracks due to a soft-soldering operation. Experiments were made with test-pieces of a number of steels, by stressing the specimen during exposure to molten metals and alloys at temperatures up to 400° C. Cracking occurred in several of the steels, and microscopic examination showed characteristic intercrystalline penetration by the molten metal. The steels varied in their behaviour, certain specimens being particularly sensitive. Tests were made to determine the effects of the temperature of the molten metals and the treatment of the steel. The nature of the type of attack studied and its practical significance are discussed.

Application of Wear-Resistant Alloys to Steel Mill Equipment. E. E. Le Van. (International Acetylene Association: Iron Age, 1935, vol. 135, Jan. 10, pp. 30–34). The author shows a number of applications of hard facings for the protection of the wearing surfaces of equipment used in steel plants. The factors to be considered in the choice of hard-facing materials are discussed.

Flame Machining and Its Effect on Steel. E. E. Thum. (Metal Progress, 1934, vol. 26, Dec., pp. 35–39). The article outlines some of the major applications of flame cutting and machining by means of the oxy-acetylene blowpipe. Mention is made of the cutting of wing-type ingots so as to remove the segregated centre portion. Cutting machines for flat plates, pipes, &c., may be operated manually or mechanically, and by employing templates or tracing devices it is possible to follow almost any contour. The oxygen torch may be used to cut bevels and grooves, while the de-seaming of billets by this process is said to furnish results superior to those obtained by other methods.

Flame-Cutting Curved Plates for Boulder Dam Penstocks. W. S. Walker. (Iron Age, 1935, vol. 135, May 2, pp. 16–21). The immense size of the Boulder Dam project necessitated the introduction of new methods and machines. Among these were the flame-cutting appliances used for fashioning the plates of which the 30-ft. diam. penstocks are constructed. This applies more particularly to the outlet nozzles and branches, for which complicated shapes were required. Flame-cutting machines were employed, and by making suitable alterations to standard appliances it was possible to cut difficult profiles.

Oxy-Ferrolene Cutting and Welding. (Engineering, 1935, vol. 139, Jan. 25, p. 99). Brief particulars are given of the apparatus used in the Oxy-Ferrolene process. Coal gas is used which is impregnated with a liquid in order to lower the ignition point and retard the propagation of the flame. The cutting action of the gas is also markedly increased. The apparatus is said to require much less attention than an acetylene generator.

MISCELLANEOUS.

The Drikold Shrinking Process. (Machinery (Lond.), 1934, vol. 45, Dec. 6, p. 379). Illustrated particulars are given of the shrinking bath used in the Drikold process for making shrinkage fits by the use of solid carbon dioxide.

Dry Ice and Alcohol Used to Shrink Hub in Girder. A. W. Brown and E. V. David. (Steel, 1935, vol. 96, Jan. 4, pp. 22–24). In the construction of four 95-ft. girders to be used on a bascule bridge, a bearing hub had to be shrunk-in in each girder. This was accomplished by the use of solid carbon dioxide (dry ice) and alcohol in specially constructed containers. The operations involved in carrying out this work are described.

Note on Frictional Resistance of Steel and Brass in Shrink Fits. W. H. Swanger. (Proceedings of the American Society for Testing Materials, 1934, vol. 34, Part II., pp. 165–171). Shrink fits carried out by refrigerating the inner member offer an alternative when expansion of the outer member by heating is not practicable or permissible. The author presents data on the resistance to axial slip developed between cylindrical rings 1 in. long and 1 in. in internal diameter assembled on pins which at room temperature were about 0·0015 in. larger in diam. Prior to assembly, the pins were contracted by cooling to – 80° C. in a bath of acetone containing dry ice. Three combinations of material were used, namely, a brass ring on a brass pin ; a steel ring on a brass pin ; and a steel ring on a steel pin. The resistance to slip was in part dependent on the amount of " oversize " of the pin, but was considerably increased when seizing occurred between the contacting surfaces.

Surface Finish and How it Can be Measured and Specified. E. J. Abbott. (Iron Age, 1935, vol. 135, Jan. 31, pp. 23–26). Particulars are given of the use of an instrument known as the Profilograph for tracing over the surface of metal objects with a very sharp diamond point. The movements of the point are magnified and the surface irregularities of the part under test are recorded optically.

Modern Polishing on a Production Basis. F. B. Jacobs. (Iron Age, 1934, vol. 134, Dec. 6, pp. 16–19). An illustrated account is given of the methods adopted at the plant of the White Sewing Machine Co., Cleveland, Ohio, for the polishing of metal parts.

Sandblasting. K. Hill. (Institute of Vitreous Enamellers : Foundry Trade Journal, 1935, vol. 52, Jan. 17, pp. 55–60). The types of machines used for sandblasting are described.

Cleaning and the Descaling of Steel. (Iron and Coal Trades Review, 1935, vol. 130, Mar. 8, p. 417). Brief particulars are

given of the Dreibrite process for removing scale and oxide from steel. The metal parts to be cleaned are subjected to scouring, the medium employed being steel grit or shot carried in suspension in low-pressure air.

Special Electrical Drives for Steel Cleaning and Processing Machines. A. M. MacCutcheon and W. R. Hough. (Iron and Steel Engineer, 1934, vol. 11, Nov., pp. 436–446). The authors describe the features of electrical drives used for various purposes in steel plants, including drives for continuous pickling plants, for cleaning and drying machines, tinning machines, continuous galvanising plants, drop-hammers, and the Budd-McKay sheet processing machine.

New Type Solvent Machines Used to Clean Metal Parts. G. E. Powers. (Iron Age, 1935, vol. 135, Jan. 17, pp. 31, 80). Brief particulars are given of the immersion type and vapour type of solvent machines for the degreasing and cleaning of metal parts.

The Steel Ball : Early Methods of Manufacture. C. Watts. (Engineer, 1934, vol. 158, Dec. 28, pp. 634–636). The advent of the pedal-propelled vehicle led to the substitution of ball for plain bearings. In order to produce the balls a new technique was gradually evolved. Initial difficulties were met with in turning the balls ; the adoption of the Hillman machine was a great advance in this respect. Later on other machines of improved design were used. The balls were subjected to a simple works examination which was not very stringent. Many types of ball-grinding machine were designed, and progress was sufficient to call for new methods of ball-gauging ; the gauge limits improved from $\pm$ 0·001 in. in 1890 to $\pm$ 0·0005 in. in 1892, whilst in 1920 it was possible to obtain balls with variations in size and roundness of not more than 0·00005 in. At first, ball races of the cup and cone type were used ; attention was afterwards devoted to the production of suitable thrust races, and self-aligning ball-races were subsequently introduced. In the early days failures were often attributable to faulty mounting and lubrication, but the importance of these factors is now properly understood.

The Manufacture of Files. (Machinery (Lond.), 1934, vol. 45, Nov. 29, pp. 333–337). Illustrated particulars are given of the equipment and methods used at the plant of J. J. Saville and Co., Ltd., Sheffield, in the production of all standard types of files.

Modern Super-Hard Cutting Materials. H. Beeny. (Midland Metallurgical Societies, Mar. 7, 1935 : Iron and Coal Trades Review, 1935, vol. 130, Mar. 22, p. 487). An outline is given of the production of carbide cutting tools, and the factors to be observed in their use for the machining of metals are discussed.

Tool Steels—Their Composition and Use. F. D. Stranner. (Steel Treatment Research Society, Australia : Heat Treating and Forging, 1934, vol. 20, Oct., pp. 482–485).

Performance of Cutting Fluids When Sawing Various Metals. O. W. Boston and C. E. Kraus. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 527–531). A series of tests was performed on a high-speed hacksaw. The tests were of two types, (*a*) the first to determine the influence of four typical cutting fluids on the wear of tungsten-steel blades ; (*b*) the second to determine the influence of eleven cutting fluids when sawing each of eight different metals, using high-speed steel blades. It is shown that a mineral-lard oil gives rise to the greatest wear, followed by plain mineral oil, an oil emulsion and a sulphurised oil, in that order. These tests were made on a free-cutting steel. In the second series of tests it was found that the effect of the cutting fluids varied with the metal sawn, the greatest variation being obtained with steels.

Progress in the Sintering of Metal Powders. W. D. Jones. (Metallurgist, 1935, vol. 10, Feb. 22, pp. 10–13). A discussion of the main points to be considered in the production and sintering of metal powders.

PICKLING.

Bullard-Dunn Process Used to Clean Car Parts. (Iron Age, 1934, vol. 134, Dec. 20, pp. 28–30). The removal of scale, grease and dirt from finished machined parts such as gears is carried out in an automobile works at Detroit by means of the Bullard-Dunn electro-chemical process. The procedure adopted is described.

A New Process for the Cleaning of Metals. U. C. Tainton. (Wire Association, Oct. 2, 1934 : Wire and Wire Products, 1934, vol. 9, Nov., pp. 399–400). It is stated that at the Sparrows Point plant wire for electro-galvanising is cleaned by making it the anode in an electrolytic bath of fused sodium salt. The advantages of the method are pointed out, but no operating particulars are given.

Continuous Pickler Rolls are Faced with Rubber. W. E. Genung. (Steel, 1935, vol. 96, Apr. 15, pp. 49–50). The advantages of rubber-faced carrier rolls for use in the continuous pickling of sheets and strip are briefly summarised.

Pickling Problems. J. W. Jenkin. (Midland Metallurgical Societies, Feb. 12, 1935 : Iron and Coal Trades Review, 1935, vol. 130, Feb. 22, p. 339). A number of aspects of the problem of pickling iron and steel are discussed.

Acid Pickling. W. Hall. (Wire Industry, 1935, vol. 2, Feb., pp. 57–58). This article deals with the action of the pickling solution in removing scale on steel articles, the advantages and

demerits of this method of de-scaling, and the effect of inhibitors. The latter restrain the attack of the acid, reducing hydrogen evolution and surface pitting; it is essential that the inhibitor used should be efficient.

Recent Investigations on the Pickling of Iron. W. Machu. (Korrosion und Metallschutz, 1934, vol. 10, Dec., pp. 277–288). The author has investigated the action of inhibitors in pickling solutions. After proving experimentally that, at low concentrations, the viscosity of a gelatine solution is proportional to the concentration, he shook up weighed quantities of finely powdered iron and of pulverised iron oxide in gelatine solutions of various strengths; from the change in viscosity of the liquid he calculated the amount of gelatine adsorbed on the surfaces of the particles. The results obtained with weakly acid and weakly alkaline solutions and iron were similar. The oxide adsorbed much less gelatine than the metallic iron; this affords an explanation of the differential behaviour of the inhibitor in regard to iron and scale in the pickling process. The equilibrium conditions in the solutions are discussed. The "free surface" of the adsorbed layer (that is, the proportion of the metallic surface left entirely uncoated and in an active condition) was measured by a method based on the relationship between this factor, the passivification time and the initial current density; the value obtained was about 0·5, and the layer contained about 50 per cent. of pores. The resistance of the passivifying layer increased considerably in the presence of gelatine. From these results the author concludes that the adsorbed layer probably consists of a spongy or diaphragm-like structure of small molecular groups of gelatine containing innumerable pores. The layer of colloid has its effect, not because it contains few pores, but because the capillary spaces between the molecular groups are so narrow. The velocity of diffusion and migration, and hence the supply of ions in the boundary layer, are greatly diminished. Any hydrogen/colloid or sulphuric-acid/colloid complexes present are held back as though by an ultra-filter.

Making Sulphuric Acid from Spent Pickling Liquor. S. F. Spangler. (Steel, 1935, vol. 96, Apr. 15, pp. 57–58). **Reconditioning Pickling Solutions.** S. F. Spangler. (Iron Age, 1935, vol. 135, Apr. 11, pp. 11, 64–66). An outline is given of a process for the reclamation of spent pickling liquor. In this process the solution is neutralised with iron oxide and evaporated in a rotary dehydrator. The iron sulphate produced is decomposed in a rotary roaster, producing (*a*) sulphur dioxide and (*b*) iron oxide cinder, of which part can be utilised for the neutralisation of additional sulphate solution. The sulphur dioxide is converted into sulphuric acid of any desired strength in a standard contact acid producing plant using a vanadium catalyst.

Surface Cracking of Steel Castings During Pickling. C. W. Briggs and R. A. Gezelius. (Metals and Alloys, 1935, vol. 6, Feb., pp. 39–40). Steel castings are found to be as susceptible to hydrogen cracking after pickling as the wrought metal. Experiments were carried out on ordinary pickled specimens, and on specimens cast so as to retain large internal stresses. In the latter case pickling produced a substantial embrittling effect, compared with unpickled specimens. It is concluded that a specimen entirely free from internal stresses would not exhibit embrittlement on pickling ; annealing does not appear to eliminate these stresses entirely.

COATING OF METALS.

(For Corrosion of Metals, see p. 516.)

Attractive Finish Helps Metal Products Sales. H. R. Simonds. (Iron Age, 1934, vol. 134, Dec., 13, pp. 16–19, 74 ; 1935, vol. 135, Jan. 17, pp. 22–26 ; Feb. 14, pp. 20–25 ; Feb. 28, pp. 24–25, 68 ; Mar. 14, pp. 14–17, 69 ; Mar. 28, pp. 25–27, 70 ; Apr. 18, pp. 14–17, 72). The continuation of a series of articles devoted to metal finishing. (*see* Journ. I. and S.I., 1934, No. II. p. 623).

Metallic Protective Coatings. I. G. Slater. (Sheet Metal Industries, 1935, vol. 9, Mar., pp. 139–140 ; Apr., p. 199). An outline is given of the more commonly used methods of producing metallic coatings.

Metal Protection by Electrodeposition. S. Wernick. (Metal Industry, 1935, vol. 46, Jan. 11, pp. 78–80 ; Jan. 18, pp. 104–106). The author reviews the methods of plating in use, including the electrodeposition of nickel and chromium, and of anodic deposits, such as zinc and cadmium, on ferrous materials.

Methods of Suspension in Electrodeposition Practice. C. F. J. Francis-Carter and B. J. R. Evans. (Electrodepositors' Technical Society, 1935, Jan. 16 : Metal Industry, 1935, vol. 46, Feb. 1, pp. 153–154). The usual methods of suspension, namely, copper wire, suspenders, and wired frames receive attention ; the special case of chromium plating is noted.

Some Further Principles of Electro-Chemistry applied to Electrodeposition. No. V.—Mixed Electrolytes. S. Field. (Metal Industry, 1935, vol. 46, Jan. 18, pp. 103–104). The conductance and throwing power of mixed electrolytes are discussed.

Some Further Principles of Electro-Chemistry applied in Electrodeposition. No. VI.—Coulometers. S. Field. (Metal Industry, 1935, vol. 46, Feb. 15, pp. 199–200). The author discusses the measurement of amounts of electricity by gas, copper and silver coulometers.

Some Further Principles of Electro-Chemistry applied to Electrodeposition. No. VII.—Complex Salts. S. Field. (Metal Industry, 1935, vol. 46, Apr. 5, pp. 389–390). This article treats of transport numbers (ionic velocities) and the behaviour of complex salts.

Significance of Anode and Cathode Efficiencies. C. B. Young. (Steel, 1934, vol. 95, Nov. 19, pp. 38, 51). The author shows some effects of variation of the anode and cathode efficiencies in electroplating.

The Effect of Oxidising Agents on Nickel Deposition. I.—Hydrogen Peroxide and Nickel Nitrate. A. W. Hothersall and R. A. F. Hammond. (Faraday Society and Electrodepositors' Technical Society, 1934, Dec. 19: Metal Industry, 1935, vol. 46, Feb. 15, pp. 201–202; Mar. 1, pp. 251–254). Oxidising agents are widely used to prevent pitting during the electrodeposition of nickel. The authors have studied the influence of hydrogen peroxide and nickel nitrate, as oxidising agents, on the cathode efficiency, hardness of the deposit, cathode potential and gas discharge at the cathode. The action of these materials in inhibiting pitting appeared to be identical with their effects in diminishing gas discharge.

The Structure and Properties of Nickel Deposited at High Current Densities. W. Blum and C. Kaspar. (Faraday Society, Mar. 30, 1935: Metal Industry, 1935, vol. 46, May 3, pp. 489–491). Details are given of experiments upon the deposition of nickel at high current densities and under a variety of operating conditions.

Electrodeposits of Nickel-Iron Alloys. E. Raub and E. Walter. (Zeitschrift für Elektrochemie, 1935, vol. 41, Mar., pp. 169–174). The influence of the addition of various materials to nickel baths on the injurious effects of iron was investigated. The possibility of the preparation of nickel-iron deposits was explored. The *p*H value was found to have considerable influence on the character of the deposits. Citric acid and tartaric acid were found to be of practical value in obtaining coherent deposits, but with lactic acid the deposits were powdery and non-adherent. Attempts to produce iron-nickel alloy deposits by electrolysis led to negative results.

Studies in the Theory of Chromium Electrodeposition. R. R. Rogers. (Electrochemical Society, 1935, Preprint 68–1). Certain metals have been successfully deposited from aqueous solutions, but others have not proved suitable for electrodeposition. To investigate this point, and especially the case of chromium—which is rather difficult to deposit—the author studied the results obtained from baths containing varying amounts of CrO_4, SO_4 and Na radicals at different current densities and temperatures. The author concludes that: The film of liquid immediately in contact with the cathode is more alkaline than the main body

of the bath ; the *p*H value of this film must lie within certain limits ; the reduction of chromium to the metallic state is due to atomic hydrogen at the surface of the cathode and not to a mere exchange of electrons between the cathode and positively charged metal ions ; this concentration of atomic hydrogen must be sufficient to reduce the metal hydroxide but insufficient to give rise to an excessive amount of chromium hydride. The mechanism of deposition may be indicated by: $Cr^{++} + 2(OH^-) = Cr(OH)_2$ (due to the alkaline film at the cathode) and $Cr(OH)_2 + 2H = Cr + 2H_2O$ (due to the atomic hydrogen). It is suggested that this theory may apply to other metals besides chromium.

Cadmium-Zinc Alloy Plating from Acid Sulphate Solutions. C. G. Fink and C. B. F. Young. (Electrochemical Society, 1935, Preprint No. 67–13). The possibility of utilising a mineral acid bath for the deposition of cadmium-zinc alloys was investigated, the effects of temperature, current density, hydrogen-ion concentration, metal ion concentration, addition agents and agitation being examined. It was found that : Agitation and increased temperature of the bath augment the cadmium content of the cadmium-zinc alloy deposit, whilst increases in current density, acid content, addition salts and agents, all increase the zinc content of the deposit. Addition agents appear to exert a selective action. The composition of a recommended sulphate bath is given.

Electrodeposition of Iron for Wearing and Bearing Metal. D. R. Kellogg. (Metals and Alloys, 1935, vol. 6, Apr., pp. 97–99). Some details are furnished of a process of building up worn parts by plating with electrolytic iron. An alkaline electrolytic cleaning bath was used, followed by an electrolytic acid bath in order to render the parts passive. The electroplating bath was a solution of ferrous ammonium sulphate containing ferrous carbonate and powdered charcoal as improvers. Good results were obtained with cold solutions, but the use of hot baths greatly increased the permissible rate of deposition. The process enables cast iron to be plated as well as steel. The deposits are stated to be hard, adherent and readily machinable.

The Microstructure of Electrodeposited Coatings. A. W. Hothersall. (Midland Metallurgical Societies and Electrodepositors' Technical Society, Jan. 3, 1935 : Metal Industry, 1935, vol. 46, Feb. 1, p. 151). This article is a summary of the author's paper. It deals with the factors affecting microstructure and hardness of electrodeposited coatings.

The Determination of the Structure of Electrodeposits by Metallurgical Methods. D. J. Macnaughtan and A. W. Hothersall. (Metal Industry, 1935, vol. 46, Apr. 19, pp. 439–441). This article is a condensed version of a paper presented to the Faraday

Society. Nickel is the metal chiefly dealt with, although other ferrous and non-ferrous metals were examined. The hardness and microstructure of the deposits were investigated, and the preliminary results are tabulated.

Studies in Zinc Electrodeposition : Deposition from Ammonium Sulphate–Zinc Baths. R. R. Rogers and E. Bloom, jun. (Electrochemical Society, Preprint 67–8). Laboratory investigations were made in order to determine the range of compositions from which zinc deposits may be obtained when using ammonium-sulphate-zinc baths. Aqueous solutions employing zinc sulphate, zinc oxide, ammonium sulphate, sulphuric acid, and ammonium hydroxide were made up. The variables NH_4, SO_4, and Zn were plotted on ternary diagrams, for both acid and alkaline solutions. From these diagrams it was possible to choose points corresponding to certain bath compositions, and further to investigate these solutions. The results are given in tabular form.

A Further Study of Cyanide Zinc Plating Baths Using Al-Hg-Zn Anodes. A. K. Graham. (Electrochemical Society, Preprint 67–12). Zinc cyanide baths of 0·56, 0·75 and 1·0 normality and containing 3 to 7 oz. per gal. of sodium hydroxide were studied, the cathode efficiencies and character of the deposits at varying current densities (20, 40 and 60 amp. per sq. ft.) being examined. Al-Hg-Zn anodes were used and excellent deposits were obtained. The results of these experiments are presented.

Improved Coating Applied to Wire by Electrogalvanising. (Steel, 1934, vol. 95, Dec. 24, pp. 22–24). Brief particulars are given of the electrogalvanising of wire at the plant of the Bethlehem Steel Co., Sparrows Point, Maryland.

Galvanising. W. G. Askew. (Wire Industry, 1935, vol. 2, Feb., pp. 65, 66, 71 ; Mar., pp. 89, 91 ; Apr., pp. 135, 137). The author reviews the four methods in general use : Hot-galvanising ; Sherardising ; electrodeposition ; and metal spraying (the Schoop process). The merits of the processes are examined.

Sales Appeal of Hot-Dip Zinc Coatings. W. G. Imhoff. (Iron Age, 1934, vol. 134, Nov. 22, pp. 10–13). The author classifies the different types of spangles found on galvanised coatings and discusses the utility of each type from the sales point of view.

Electrolytic Tinplating. M. Schlötter. (Metallwirtschaft, 1935, vol. 14, Mar. 29, pp. 247–250). The author reviews the past and present state of development of the electrodeposition of tin. He compares the properties of electrodeposited tin with those of tin coatings produced by the hot-dipping process, by reference to tests made on tin-plated copper wire.

The Development of the Tinplate Industry in Great Britain. (International Tin Research and Development Council, Bulletin No. 1, Feb., 1935, pp. 69–79). The history of the introduction

of tinplate manufacture into England, and the technical developments in tinplate production are traced.

Some Modern Uses of Tinplate. (International Tin Research and Development Council, Bulletin No. 1, Feb., 1935, pp. 57–65).

Tinplate—Some Fundamental Considerations. W. E. Hoare. (Swansea Technical College Metallurgical Society, Dec. 15, 1934 : Sheet Metal Industries, 1935, vol. 9, Mar., pp. 133–135, 137 ; Apr., pp. 201–204). The author begins by discussing the characteristics and behaviour of the compound $FeSn_2$, which is known to exist in tinplate. He goes on to examine the effect of the alloy layer ($FeSn_2$) at the steel-tin interface, and describes the reactions which take place in the tinpot during the tinning operation. Then follows a discussion of porosity. The author distinguishes between normal pores (complete discontinuity) and potential pores (partial penetration of the coating) ; reasons for the formation of these pores are advanced.

The Determination of the Porosity of Tin Coatings on Steel. D. J. Macnaughtan, S. G. Clarke, and J. C. Prytherch. (International Tin Research and Development Council, 1935, Jan., Series A, Technical Publication No. 7). This paper is based on a previous study of the subject by the authors (*See* Journ. I. and S.I., 1932, No. I. pp. 159–174). They now give details of improved degreasing processes. One method uses a 1 per cent. solution of sodium disilicate after treatment with carbon tetrachloride. A cathodic degreasing process is also described in which 0·5 per cent. sodium carbonate is used as the electrolyte. The specimen is connected to the negative pole, a 4-volt supply being used ; the current is applied for 1 min., and the hydrogen bubbles which form remove the film of grease. For highly resistant films the surface is first cleaned with carbon tetrachloride and a thin coat of Necol varnish applied.

Examination of Tin Coatings on Tinplate. (Sheet Metal Industries, 1935, vol. 9, Jan., pp. 12, 18). An abridged English translation of an article by F. Eisenkolb describing a method for determining quantitatively the weight of a tin coating on tinplate. The original article appeared in Stahl und Eisen, 1934, vol. 54, Feb. 1, pp. 109–110 (*See* Journ. I. and S.I., 1934, No. I, p. 545).

Testing and Controlling Metallic Coatings on Wire. J. H. Hruska. (Wire and Wire Products, 1935, vol. 10, Jan., pp. 9–11, 46). Particulars are given of the Glazunov test for determining the thickness and weight of metallic coatings. The practical applicability of the test is discussed.

A Study of the Yellow Stain on Tinplates. C. E. Beynon and C. J. Leadbeater. (International Tin Research and Development Council, 1935, Technical Publication, Series D, No. 1). It has been shown that yellow stain on tinplate is due to surface oxidation of the tin in accordance with the differential aeration principle.

The difficulties experienced in lithographing yellow-stained sheets cannot be attributed to the stain as such. When stained sheets have been stoved at 140° C. or washed with methylated spirits they will print quite satisfactorily.

It is believed that the effect of these treatments is to remove the film of oil or grease and that the presence of such films of grease causes the yellow-stained portions of tinplate to be incapable of being printed satisfactorily. Commercially stained sheets can be made to take the print, by first subjecting them to a cathodic reduction treatment. In this case the stain itself is removed, as well as any grease that might be associated with it.

It is not yet known whether tinplates which are perfectly free from grease would be less prone to develop yellow stain on being packed and stored, but there can be very little doubt that if they became stained they would not present any difficulty from the point of view of printing. A chemical method of cleaning the sheets might prove much more efficient than the mechanical methods now in use. There appear to be favourable prospects in the use of trichloroethylene vapour as a degreasing medium. The running costs should not be prohibitive, and improvements in some important subsidiary directions would probably be achieved.

Coating Machine Elements by Metal Spraying. C. Boyden. (Iron Age, 1935, vol. 135, Jan. 10, pp. 35–37). The author discusses the application of the metal spraying process to the building-up of worn and corroded metal surfaces, and describes correct procedure.

Preparing Machine Elements for Metal Spray Coating. C. Boyden. (Steel, 1935, vol. 96, Feb. 18, pp. 34–35). It is recommended that for cylindrical work a thread be roughly cut on the surface of the part to be coated ; in this way good adhesion is obtained. The metal is sprayed on with a gun in the usual way.

Protective Metallic Coatings. W. E. Ballard. (Manchester Association of Engineers, 1934, Dec. 7 : Iron and Coal Trades Review, 1934, vol. 129, Dec. 14, p. 929). During the process of metal spraying from wire by means of a pistol, the particles of metal are torn from the wire and blown at high velocity on to the surface to be treated. On impact the particles form saucer-shaped discs which interlock ; little or no oxidation occurs during spraying. The coating may be applied to non-metallic surfaces. Large steel structures may be sprayed with aluminium, and, on heat-treating, a film forms which gives rise to a protective oxide coating ; this is corrosion-resistant to a high degree.

The Reconditioning of Defective Metal Parts. (Engineering, 1935, vol. 139, Apr. 19, p. 415). Information is given concerning a process for repairing defects using a cast-iron alloy (Gussolit) which is melted into the preheated component, and a method

of spraying metal by means of an oxy-hydrogen blowpipe and a blast of compressed air (the Schliha process).

Some Aspects of Plant Layout and Production. J. T. Gray. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1935, vol. 52, Feb. 7, pp. 107–110; Feb. 14, pp. 123–126: Sheet Metal Industries, 1935, vol. 9, Mar., pp. 161–163; Apr., pp. 217–218; May, pp. 319–322). An account is given of the equipment and layout of plant for the production of enamelled ware, including iron castings.

Vitreous Enamelling of Cast Iron. B. B. Kent. (Institute of British Foundrymen: Foundry Trade Journal, 1934, vol. 51, Dec. 13, pp. 375–376). The author discusses sand-blasting and shot-blasting, the preparation of the enamel, spraying, drying and fusing.

Factors to Increase Production in Enamelling Plants. B. B. Kent. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1935, vol. 52, Apr. 11, pp. 246–248, 260). An installation for a jobbing plant is described in detail; emphasis is placed on design and layout.

Porcelain-Enamelled Tile Made on a Mass Production Basis. F. L. Prentiss. (Iron Age, 1935, vol. 135, May 9, pp. 12–13, 94). The tiles are of steel, and the enamelling equipment is largely automatic in operation; a formed tile is enamelled and ready for packing 12 min. after being placed on the conveyor line. The flanged tiles are stamped from 20-gauge sheet steel, pickled, dried, placed on the conveyor, sprayed, dried, burnt and finally packed.

Enamelling and De-Enamelling Feature Finishing of Washing Machine Tubs. F. L. Prentiss. (Iron Age, 1935, vol. 135, May 16, pp. 26–29, 74). The tubs are drawn from circular blanks, conveyed to the pickling room and so to the enamelling department. The de-enamelling plant consists of an alkaline bath of molten sodium hydroxide, electrically heated. Defective parts are de-enamelled, washed, sand-blasted and returned to the conveyor line.

Titanium Compounds and Application thereof in Vitreous Enamels. C. J. Kinzie and J. A. Plunkett. (Journal of the American Ceramic Society, 1935, vol. 18, Apr., pp. 117–122). A study was made of the effect of titanium oxide and certain other oxides on the thermal dilatation, melting point and fusion flow properties of a simple enamel glass. The frits produced by titania additions were very fluid and generally coloured.

Strength and Young's Modulus of some Ground-Coat Enamels for Sheet Iron. W. N. Harrison, S. M. Shelton, and W. H. Wadleigh. (Journal of the American Ceramic Society, 1935, vol. 18, Mar., pp. 100–106). A number of enamel compositions of the sheet-iron ground-coat type were studied, and tests were carried

out for Young's modulus, tensile strength and modulus of rupture ; these properties were correlated with the composition.

The Adjustment of Enamels to Sheet Metal. A. Dietzel and K. Meures. (Journal of the American Ceramic Society, 1935, vol. 18, Feb., pp. 37–38). It is shown that the coefficient of expansion decreases from the sheet steel, through the ground coat to the cover enamel.

Micro-Gas Analysis of Gas Trapped in Vitreous Enamels on Enamelling Iron During Firing. S. E. Freeman and V. W. Meloche. (Journal of the American Ceramic Society, 1935, vol. 18, Apr., pp. 123–125). The enamels were crushed beneath a glycerine-brine solution and the gas was collected in a tube and subjected to micro-analysis. The results of these analyses are presented.

Manufacture and Some Uses of Nickel-Clad Steel. H. R. Simonds. (Iron Age, 1935, vol. 135, Jan. 24, pp. 14–17). Particulars are given of the methods adopted at the plant of the Lukens Steel Co., Coatesville, Pa., for the production of nickel-clad steel plate. Blooms are rolled down to plates $2\frac{1}{4}$ in. in thickness, trimmed to size and sand-blasted. The usual proportion of thickness of nickel to steel is 1 to 9. Two nickel-clad plates are rolled together, the assembly being as follows : A steel plate, a nickel plate, a parting compound, a nickel plate and a steel plate. The two steel plates project beyond the nickel plates and the whole assembly is sealed by welding across the edges of the steel plates. Before rolling, the assembly of plates is heated slowly up to 2,400°. The first rolling pass creates the bond between the nickel and the steel, and subsequent rolling is merely to reduce the plates to the desired thickness. After rolling, the edges are sheared and the two bonded plates separated.

Plated Sheet and Working it up. K. Halfmann. (Zeitschrift des Vereines deutscher Ingenieure, 1934, vol. 78, Dec. 8, pp. 1421–1422). After mentioning the four general methods of producing layers of metals—such as nickel, copper-nickel, copper, brass—on the surface of mild-steel sheets, the author touches briefly on the properties of such sheets produced by a welding process, in which the " plating metal " and the basis steel are welded together and the product is hot-rolled, and then deals with the working-up of such composite sheet into various forms and shapes.

The Determination of the Suitability of Bituminous Coatings for Underground Pipes. G. O. Thomas. (Journal of the Institution of Engineers, Australia, 1934, vol. 6, Oct., pp. 337–346). The author deals with the testing of bituminous materials for pipe coatings. Standard methods of testing are discussed, methods evolved to obtain data not available from standard methods are described, and some results are given. The most important

of these is the determination of the rate of absorption of water by the material. A rational method of determining the economic thickness of coating is also discussed.

A Proposed Method for Testing the Adhesion of Rubber to Metal. A. H. Flower and H. E. Wening. (Proceedings of the American Society for Testing Materials, 1934, vol. 34, Part I. pp. 525–531).

Metal Priming Paints. H. A. Nelson. (Industrial and Engineering Chemistry, 1935, vol. 27, Jan., pp. 35–41). Metal priming paints are considered as pigment-vehicle combinations subject to chemical and physical changes. The different theories of corrosion are briefly reviewed, and the external agents required to promote corrosion according to each theory are discussed. It is known that the most essential of these are supplied within the film by changes in oils and resins, the most obvious being water, carbon dioxide, and acid materials. The fact that a cathodic depolarising agent (oxygen) is also supplied in a very active form as hydrogen peroxide has apparently been overlooked. Basic pigments that are good neutralising agents are desirable in priming paints ; so also is the ability of the pigment to form reaction products that add to the physical qualities of the film. A metal priming pigment should also have more or less ability to control depolarising agents (such as hydrogen peroxide) given off by the vehicle component. It may do this (1) because its combinations with the vehicle (soaps) exist in several stages of oxidation, the lower stages being able to reduce hydrogen peroxide, as in the case of the lead oxides ; (2) because the pigment reacts to make a reducing agent such as hydrogen available, as in the case of metallic zinc powder ; or (3) because there is maintained in the film a state of alkalinity or other condition under which hydrogen peroxide is decomposed. The oxidation of the pigment by hydrogen peroxide must not result in the formation of reaction products that promote corrosion.

The Protection of Steelwork by Paint. W. E. Highfield. (Engineering, 1935, vol. 139, Feb. 15, pp. 177–178 ; Feb. 22, pp. 205–206). The subject is discussed under the following headings : (1) The material to be protected ; (2) the action of weather on steel if left unprotected ; (3) the preparation of the material to be protected ; (4) the method of applying the protection ; and (5) the choice of the protective coating.

Improved Paints Spur Attack on Corrosion Problems. J. O. Hasson. (Steel, 1935, vol. 96, Mar. 11, pp. 30–33). A brief survey of the various types of paints available for the protection of metal structures, and the factors to be considered in their selection.

PHYSICAL AND CHEMICAL PROPERTIES.

PROPERTIES AND TESTS OF CAST IRON.

Tests on Cast-Iron Girders removed from the British Museum. H. J. Gough. (The Institution of Civil Engineers, 1934, Selected Engineering Papers No. 161). Three main cast-iron girders and six secondary girders were removed from the British Museum and tested. The main girders were tested in pairs in a form of apparatus specially designed for the purpose. The load was supplied by hydraulic jacks and the reactions were taken by standard steel rods fitted with extensometers to enable the load to be measured. Testing was carried out in the horizontal plane. The secondary girders were tested in a laboratory machine. On examining the fractured surfaces of the main girders it was found that undetected cracks were mainly responsible for failure; blowholes and other flaws were also present. As a consequence the breaking loads were low. The secondary girders were sound and gave good values for load at fracture. Tests on specimens taken from main and secondary girders showed that the iron used was satisfactory; chemical and metallurgical examination confirmed this.

Testing the Strength Properties of Cast Iron. B. Osann. (Giesserei, 1935, vol. 22, Apr. 12, pp. 169–172). After reviewing the development of the tensile and bending tests under the influence of Emil Schrödter, the author discusses the elongation of cast iron in these tests; in the bending test the presence or otherwise of graphite crystals is of influence. The tensile test is superfluous; one should restrict oneself to the bend test and calculate the strength in tension from that in bending. The author also discusses the scatter of test results and the influence of the cross-section of the test-piece; given a free hand in the latter respect, any desired test value can be attained, as is shown by examples. The author suggests that separately-cast test-pieces should have a diameter equal to the thickness of the casting plus 30 per cent., and a length equal to twenty times the diameter; they should not be machined; they should be cast vertically, and he indicates in which way the casting fin should be disposed.

Permanent Set and Elastic Hysteresis in Cast Iron. J. E. Hurst. (Foundry Trade Journal, 1934, vol. 51, Dec. 27, pp. 405–406; 1935, vol. 52, Jan. 17, pp. 63–64, 66). Ring-shaped test-pieces were cast; gaps were cut, and the rings were stressed. Centrifugally-cast rings were found to suffer less permanent set than sand-cast specimens. The behaviour of the rings is set forth in graphical and tabular form.

Strength Tests on Cast Iron and their Evaluation by Means of the Theory of Mohr with Enveloping Parabola. A. Leon and A. Slattenschek. (Giesserei, 1934, vol. 21, Dec. 21, pp. 542–548). Of the various theories of fracture, Mohr's general theory has the advantage that it links together the "rupture fracture" (*Trennbruch*) and the shear fracture. The authors carried out tensile and compression tests on cast iron in which the inclination of the fractured surfaces was measured, and also torsional and shear tests, in order to investigate the usefulness of Mohr's theory with enveloping parabola. With the inclination of the fractured surfaces in the tensile test as the starting point, they calculated the ratio of the compression strength to the tensile strength. This ratio differed from that derived directly from the strength values; this difference is attributed to the additional bending stresses which can never be completely avoided in the tensile test, and which, under otherwise similar conditions, have a greater effect in specimens of small cross-section than in larger ones, a circumstance inherent in the tests. Not only the angle of fracture as measured in tensile and compression tests, but also the torsional and shear strengths in their relation to the tensile and compression strengths show the superiority of Mohr's theory with enveloping parabola over the usual approximations with straight-line envelopes.

The Influence of the Testing Temperature on the Specific Impact Energy to Fracture of Cast Iron. E. von Rajakovics. (Giesserei, 1935, vol. 22, Mar. 1, pp. 95–96). After pointing out the value of the impact bend test for cast iron, the author briefly describes the experiments which he has made, the specimens, the testing machine, the manner of heating or cooling the test-pieces, &c., and gives the results obtained. It is shown that the impact energy to fracture of cast iron is very much dependent on the temperature at which the test is made.

Heat-Treated Grey-Iron Cylinder Liners. W. P. Eddy, jun. (Philadelphia International Congress: Foundry Trade Journal, 1935, vol. 52, Mar. 28, pp. 219–220). The author gives the properties, heat treatment and performance of cylinder liners for heavy duty. The liners contain under 1 per cent. of combined carbon, with additions of chromium and nickel, and possess a hardness of over 500 Brinell. They are stated to perform satisfactorily.

Some Experiments on the Duplication of the Intrinsic Properties of Cold-Blast Pig-Iron. J. E. Hurst. (Foundry Trade Journal, 1935, vol. 52, Feb. 21, pp. 137–138, 141). The properties of cold-blast and other pig irons are set forth, and the problem of matching the properties peculiar to cold-blast irons while using other irons is examined. Experiments were carried out on test-bars for this purpose, and it was found that by the use of blended mixtures

the intrinsic properties of cold-blast irons could be successfully duplicated.

The Coefficient of Expansion of Cast Iron. E. Söhnchen and O. Bornhofen. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Feb., pp. 357–359). Among the elements which accompany iron, carbon has the greatest influence on the coefficient of expansion of cast iron. Decomposition of the carbide raises the coefficient. Just as in steel, large variations are produced by large additions of nickel. Copper and aluminium raise the coefficient, but with chromium additions the value rises at first and then sinks.

Decarburisation of Cast Iron by Hydrogen. W. Baukloh, W. von Kronenfels and H. Guthmann. (Stahl und Eisen, 1934, vol. 54, Dec. 27, pp. 1334–1336). The authors record the results of experiments on the decarburisation of cast irons in a stream of hydrogen. In the case of grey and white unalloyed cast irons, the decarburisation increased with the velocity of the hydrogen stream, which was varied between 100 and 900 cm. per hr. The rate of decarburisation also increased as the temperature rose from 800° to about 950°, but above this temperature it decreased again ; this is connected with the decomposition of the methane formed. It is noteworthy that above a certain temperature, which depended on the velocity of gas flow, white iron was decarburised more slowly than grey iron, while below this temperature the reverse was the case ; from this it is to be concluded that above this temperature the carbon pressure of graphitic iron is greater than that of iron containing cementite, which is in contradiction to the conception of the stable nature of the iron-graphite system. The influence of silicon, manganese, chromium, nickel and cobalt on the rate of decarburisation at temperatures between 600° and 1,000° was also investigated. The influence of these alloying elements on the rate of decarburisation was fairly distinctive. A connection with the structural diagrams has not so far been found ; for these elements it is probable that the ability of the hydrogen to diffuse is the determining factor.

The Influence of the Control of the Slag on the Structure of Pig and Cast Iron. E. Diepschlag and M. Michalke. (Giesserei, 1934, vol. 21, Nov. 23, pp. 493–496). Four hematite irons and a phosphoric pig iron were melted under various slags in an electric arc furnace ; a white iron was used for decreasing the silicon contents. Melting under an acid slag generally increased the silicon content of the metal, whereas basic slags reduced it ; the metal was largely desulphurised. In all the slags the FeO content lay between 1 and 2 per cent. In most of the specimens the graphite was finer than that in normal iron, but nevertheless large differences in the particle size of the graphite in the various specimens were observed. The structures could be grouped as

follows: (*a*) Normal graphite in a pearlitic ground-mass; (*b*) extremely fine graphite in a ferritic ground-mass (graphite eutectic); and (*c*) coarse graphite in a ground-mass of decomposition ferrite. The structures of the various specimens have been plotted in the CaO–Al_2O_3–SiO_2 triangular slag diagram at the points corresponding to the slags under which they were melted. It appears that: (i) Lime-alumina slags with low silica contents yield type (*a*) structures; (ii) lime-silica slags with high lime contents cause a strong tendency to the formation of type (*b*) structures (this applies also to high-phosphorus irons) and (iii) lime-silica slags with high silica contents produce chiefly type (*c*) structures. To the last-named group belonged a specimen with the highest oxygen content (0·0105 per cent.), whereas others with type (*a*) and type (*b*) structures contained only 0·0019 and 0·0025 per cent. of oxygen. No connection with the structures of the raw materials could be observed, so that heredity could be excluded. The eutectic temperatures of the three groups were: (*a*) 1,150°, (*b*) 1,140°, and (*c*) 1,160° C. (calculated to the same silicon content); in melts with high graphite eutectic contents crystallisation did not start until about 1,130°, but such undercooling was not observed in types (*a*) and (*c*). In unetched chilled sections, non-metallic inclusions of various sizes and in varying amounts were observed; they were crystalline and consisted obviously of oxides and silicates of iron and accompanying elements. These inclusions were particularly numerous in melts with type (*a*) and type (*c*) structures, but were much less frequent in type (*b*) structure irons. The authors discuss all the data presented, and come to the conclusion that the observed influence of the slags on the structures must arise from their different abilities to absorb from the iron the oxide constituents, which act as nuclei for the crystallisation of the graphite. The "heredity" observed in melting similar pig irons is also related to the content of these oxide inclusions.

Influence of Melting Treatment by Means of Ferrous-Oxide-Rich and Acid-Low-Protoxide Slags on the Crystallisation and Mechanical Properties of Grey Cast Iron. P. Bardenheuer and A. Reinhardt. (Giesserei, 1935, vol. 22, Feb. 1, pp. 45–52). A number of cast irons, of compositions ranging from hypo- to hyper-eutectic and containing from 0·5 to 5 per cent. of silicon, were treated at 1,500°–1,600° C. with slags of which the ferrous oxide content was regulated by additions of mill scale and glass; the chemical composition, oxygen and total gas contents, bend strength, deflection, tensile strength and Brinell hardness were determined. After treatment with ferrous-oxide-rich slag, all the irons solidified on the stable system without undercooling; on treatment with acid low-protoxide slag, crystallisation set in after undercooling. The resulting differences in structure and

in crystallisation process are dealt with fully. The mechanical properties were dependent on the differences in the structures. Treatment of low-carbon irons with glass slag caused the bend and tensile strengths to drop, regardless of the silicon content; as the carbon content increased the decrease in these properties due to this treatment lessened, until with 3–4 per cent. of carbon there was no change, and in irons with more than this amount of carbon the values of these properties increased. This treatment reduced the deflection, but was apparently without effect on the hardness. In hypereutectic irons treatment with glass slag raised the tensile strength when the silicon content was low and depressed it when the silicon content was high. In low-silicon high-carbon irons the Brinell hardness was lower after treatment with protoxide slag than with glass slag. Under the influence of the protoxide slag the hardness rose with rising silicon and falling carbon contents and was much higher than the value after glass-slag treatment. In the hypo-eutectic irons the oxide and total gas contents were higher after treatment with ferrous-oxide-rich slag and lower after glass-slag treatment; this regularity was not observable in hypereutectic irons.

Properties of Grey Cast Iron as Affected by Casting Conditions. C. M. Saeger, jun., and E. J. Ash. (Journal of Research of the National Bureau of Standards, 1934, vol. 13, Oct., pp. 573–577). An investigation into the effect of maximum heating temperatures on the physical properties of cast iron is described. (*See* Journ. I. and S.I., 1934, No. I, p. 553.)

Should a Fine-Grained Cast Structure be Developed by Correct Charging or by Superheating? How can Section Susceptibility be Avoided? B. Osann. (Giesserei, 1935, vol. 22, Feb. 15, pp. 76–78). The author favours the development of a fine-grained cast structure in cast iron by proper attention to the calculation of the charge, and indicates the steps to be taken in order to produce a eutectic molten iron which will yield castings with a eutectic structure. He gives an explanation for the refinement of the graphite by superheating, for Piwowarsky's critical point, and for the occurrence of kish graphite in the pig iron. Section susceptibility can be combated by the use of a eutectic pig iron, such as was typically produced in the charcoal blast-furnace.

The Rate of Solution of Graphite in Molten Iron. E. Piwowarsky. (Giesserei, 1935, vol. 22, June 7, pp. 274–277). The author's further tests have confirmed the results of his previous experiments (Archiv für das Eisenhüttenwesen, 1933–34, vol. 7, pp. 431–32) that even coarse graphite dissolves in molten iron with such rapidity that any influence of undissolved graphite particles on the crystallisation of graphite is out of the question.

Graphite Formation in Grey Cast Iron. H. Nipper. (Giesserei, 1935, vol. 22, June 7, pp. 280–287). The author discusses the

crystallisation of graphite in grey iron and illustrates his remarks by means of micrographs. The influence of various modes of undercooling on the structures of hypo-eutectic, eutectic and hypereutectic cast irons is explained; micrographs representing the individual conditions on freezing are reproduced. The properties to be expected in the alloys are indicated, and suggestions for the melting procedure are made.

Cast Iron for Metal Electro-Coatings. H. Reininger. (Giesserei, 1935, vol. 22, Mar. 29, pp. 148–149). A brief account is given of tests made to find a cast iron to which electrodeposited metals, such as nickel, copper and chromium, would adhere well. The size, shape and quantity of the graphite are determining factors; thick, coarsely-flaked and spheroidised forms of graphite are undesirable, for they not only give inadequate support for the plating (allowing it to be indented and broken) but they also absorb the plating solution and so give rise to corrosion under the coating.

Bearing Running Tests with Cast Iron as Bearing Material. W. Meboldt. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, May 25, pp. 629–631). After discussing a number of factors which influence the wearing properties of bearings, the author describes tests on bearings in which cast iron was used as the bearing material. Provided that the bearing surface was very carefully prepared, wear of the cast iron only set in at very high values of specific bearing pressure.

Experiments on the Influence of Additions of a High-Carbon Special Pig Iron on the Resistance to Growth and Scaling of Grey Cast Iron. M. Paschke and H. Schuster. (Giesserei, 1934, vol. 21, Nov. 9, pp. 469–476). A number of different pig-iron charges with various proportions (0 to 80 per cent.) of a high-carbon special pig iron (carbon, 3·54; silicon, 1·60; manganese, 0·94; sulphur, 0·107; phosphorus, 0·35 per cent.; manufactured by the Hochofenwerk Lübeck, A.-G., and sold under the name "H K Special Pig Iron") were melted in the cupola. Specimens were subjected to repeated heating cycles in a dilatometer to determine the resistance to growth, while the scaling resistance was investigated by heating test-pieces in a muffle furnace. The results obtained are set out in diagrammatic form, and micrographs of the structures are reproduced. The tests, particularly the repeated heating cycles between 950° and 600° C., demonstrated the superior growth- and scaling-resisting properties of the irons containing large proportions of the special pig, as compared with the irons containing only small quantities or none at all. This improvement in the properties is attributed to the finer condition of the graphite, the dense pearlitic ground-mass and the low gas content resulting from the large additions of the special pig iron.

The Influence of Phosphorus on the Growth-Resistance of Grey Cast Iron. E. Söhnchen and Piwowarsky. (Stahl und

Eisen, 1935, vol. 55, Mar. 21, pp. 340–341). A brief account is given of tests to determine the influence of phosphorus on the growth of cast irons of various carbon contents. The specimens were (*a*) heated and cooled three times between 650° and 975° C. in a dilatometer *in vacuo*, and (*b*) heated for 250 hr. at 650 ° C. in air. The dilatometer tests revealed no great influence of phosphorus ; in air, on the contrary, increasing phosphorus decreased the growth considerably in the case of irons with about 3·3 per cent. of carbon, though less in irons with only about 2·8 per cent. In the form of steadite, the phosphorus prevents the ingress of oxygen (the cause of growth) when it occurs as a network and completely envelops the pearlite grains. For the production of a growth-resisting iron, finely divided steadite or a broken-up network structure are disadvantageous.

Modern Cast Iron and its Possible Applications in Construction. A. Thum. (Giesserei, 1935, vol. 22, May 10, pp. 214–218). The author surveys progress in the development of the mechanical properties of cast iron, compares it with steel under tensile and alternating stresses, discusses the durability of structural parts made of cast iron, and touches on the future of the uses of cast iron in new directions in constructional work.

Modern Cast Irons in Chemical Engineering. J. G. Pearce. (Chemistry and Industry, 1934, vol. 53, Dec. 14, pp. 1052–1058). This paper constitutes a survey of the types of cast iron now available. The author points out that irons consisting of small graphite flakes embedded in a pearlite matrix have replaced irons containing coarse graphite in a ferrite-pearlite matrix. Graphitising agents are introduced into the ladle in order to convert a white iron into a grey iron in which the graphite is finely divided. Such irons possess enhanced mechanical properties, but they are more difficult to cast. Alloy additions tend to improve soundness, uniformity of structure and strength. Ordinary cast iron is often found to be highly resistant to certain corroding conditions ; but alloy cast irons are better in this respect. Small additions of nickel bring about a useful improvement, whilst the 12–16 per cent. silicon irons show marked resistance to acids. The austenitic nickel-bearing cast irons are both corrosion- and heat-resisting, stronger than grey iron and easily machinable. They contain from 1·8 to 3 per cent. of carbon, and either 14 per cent. nickel, 6 per cent. chromium and 5 per cent. copper (Niresist), or 6 per cent. silicon, 18 per cent. nickel, and 2 per cent. chromium (Nicrosilal). Silicon confers resistance to growth at elevated temperatures ; Silal, containing from 4 to 10 per cent. of silicon resists both growth and scaling well. High-chromium irons, with from 1 to 3 per cent. of carbon, and about 35 per cent. chromium, possess non-corroding properties and are analogous to the stainless steels.

Note on Corrosion-Resistant Cast Irons. L. Bovet. (Arts et Métiers, 1934, vol. 87, Dec., pp. 276–277). The corrosion-resistance of nickel cast irons and nickel-copper-chromium cast irons is briefly discussed.

Alloy Cast Irons. A. T. Weare. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, May 9, p. 318). The properties and uses of alloy cast irons are briefly considered.

Alloy Iron Castings. (Metallurgia, 1934, vol. 11, Dec., pp. 39–41). On account of its cheapness and the ease with which it can be moulded, cast iron remains the most important casting alloy. Alloy additions greatly increase its usefulness by improving the mechanical properties. Nickel and chromium confer added strength and toughness, whilst quite small percentages of molybdenum enhance the physical properties and refine the grain. Molybdenum may be added in the ladle, but nickel and chromium are better introduced into the cupola. Irons containing fairly high proportions of alloying elements are austenitic, and strongly resistant to acids; they are also easier to work than the acid-resisting silicon irons.

Recent Developments in Cast Iron. W. West. (Metallurgia, 1934, vol. 11, Dec., pp. 54–56). The writer summarises the advances which have been made in the production of alloy irons. Reference is made to irons containing nickel, chromium, and molybdenum, and tables are supplied showing the improvements in mechanical properties which may be gained.

The Influence of Antimony in Pearlitic, Martensitic and Austenitic Cast Irons. E. Piwowarsky. (Giesserei, 1935, vol. 22, June 7, pp. 277–280). Tensile and hardness tests and, in particular, corrosion tests in caustic alkali and wear tests were made on cast-iron specimens containing nickel, antimony or both elements together; the specimens were tested in the pearlitic, martensitic and austenitic conditions. Antimony increased very considerably the resistance of the alloys to alkali corrosion; the addition of antimony to the extent of one-sixth or one-eighth of the nickel content of an alkali-resistant iron containing more than about 2 per cent. of nickel reduced the attack still further. The nickel additions suppressed the adverse effect of antimony on the mechanical properties, provided that the phosphorus content was low. In the heat treatment of the specimens to obtain the desired structures it was observed that antimony stabilised the pearlite; further, on annealing the martensitic material, in the presence of 1 per cent. of antimony the hardness hardly decreased while with 2 per cent. it actually increased. Tempering tests on oil-quenched specimens showed that the tempering temperature at which the decrease of hardness set in increased with the antimony content up to 2 per cent.; with 3 per cent., however, the hardness after oil-quenching dropped very considerably.

The author suggests that the hardening of the martensite with less than 2 per cent. of antimony is due to a precipitation-hardening effect, and that with more than that content of the element the nickel-rich alloys are outside the precipitation-hardening range. Antimony increased the wear resistance of the martensitic alloys. The results of the tests on the austenitic series were of less significance. Annealing caused the usual carbide precipitation, resulting in a rise of hardness. The wear resistance was hardly affected by additions of antimony.

Molybdenum in Grey Cast Iron. C. M. Lobe, jun. (Foundry, 1935, vol. 63, Jan., pp. 24–25, 59). A brief discussion of the effect of molybdenum on the properties of grey cast iron and a review of recent developments in the use of molybdenum cast iron.

Copper Additions to Grey Cast Iron. J. Hird. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 52, May 9, pp. 318–322). To improve an iron containing carbon 3·2, silicon 2·75, and phosphorus 1·0 per cent., an addition of 2·5 per cent. of copper was made. The copper-alloyed iron was closer grained and harder, although the physical properties were not otherwise greatly affected.

Malleable Iron—Its Properties and Applications. D. P. Forbes. (Joint Meeting, Western Society of Engineers, American Foundrymen's Association, and American Society of Mechanical Engineers, 1935, Mar. 18: Iron Age, 1935, vol. 135, Apr. 4, pp. 43–45). The properties and applications of malleable cast iron are discussed.

Cause of the Incompatibility Occasionally Found Between Elongation and Tensile Strength of Malleable Iron Test Bars. E. Touceda. (Transactions of the American Foundrymen's Association, 1934, vol. 42, pp. 407–417). The author has investigated the incompatibility between the tensile strength and elongation occasionally found in malleable iron test bars. This is due to a surface defect in the bars caused by a layer of very fine dirt from the sea-coal facing.

Some Effects of Copper in Malleable Iron. C. S. Smith and E. W. Palmer. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 603). A study is made of the effect of copper on the rate of graphitisation of white cast irons, and it is shown that the addition of copper accelerates the graphitisation ; 1 per cent. of copper reduces the time required by 50 per cent. Copper also improves the yield point of malleable iron, and if the castings are subjected to a precipitation-hardening treatment (heating to just below the critical point, air cooling and reheating to about 500° C.) a further increase in strength is obtained, although this is accompanied by a loss in ductility.

Effect of Copper in Malleable Iron. C. H. Lorig. (International Foundry Congress: Foundry Trade Journal, 1935, vol. 52,

Jan. 31, pp. 93–95). Copper tends to promote graphitisation in the production of a white cast iron for conversion into malleable iron. The mechanical properties are improved and the susceptibility to intergranular embrittlement is reduced.

PROPERTIES AND TESTS OF IRON AND STEEL.

Representative Samples and Commercial Testing. A. Haas. (Engineer, 1935, vol. 159, Feb. 22, pp. 202–203). The author indicates some of the reasons why sampling is, on occasion, difficult. He points out that in heavy crankshafts, for instance, specimens are taken from the least worked portion of the forging—the web. In all cases representative specimens should be chosen if possible. With manufactured articles tests on the finished product may be necessary, and here it is essential that truly random samples be examined; selection must, however, be systematic. The method of successive subdivision should be adopted. Care must be taken in testing the materials, since serious discrepancies may otherwise be introduced.

The Testing of Materials. C. H. Desch. (Proceedings of the South Wales Institute of Engineers, 1935, vol. 50, No. 6, pp. 449–474). This paper constitutes a survey of the mechanical, metallographical and non-destructive methods of testing. Particular attention is devoted to the significance of the terms in common use and the true value of the tests employed. The importance of fatigue and creep, in view of the heavy duty to which certain steels are now subjected, is also stressed. A brief account is given of the use of macro- and micro-examination and of the application of X-rays and other means of non-destructive testing.

Some Aspects of the Testing of Materials. H. J. Gough. (Iron and Steel Industry, 1935, vol. 8, Jan., pp. 117–120). Reference is made to the history of testing and to the conditions which render the adoption of full-scale testing desirable. Examples are then adduced of full-scale tests on cast-iron girders removed from the British Museum, and of fatigue tests carried out on drill pipes for oil wells. These pipes must withstand very severe service conditions; it is pointed out that only full-scale tests will give adequate information about the behaviour of the pipes when in use. The problem of the failure of metal airscrews is examined, and apparatus for investigating the effect of vibration is described. Other examples are also quoted and the need for a full-scale machine for cyclic stressing is emphasised.

New Testing Machines. R. Guillery. (Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1935, vol. 134, Apr., pp. 218–232).

2,750-kg. Tensile Machine for Small Test Bars. R. Guillery. (Revue de Métallurgie, Mémoires, 1935, vol. 32, Feb., pp. 58–60). The machine described and illustrated is intended for making tensile tests on very small-size specimens.

The Griffin-Gale Testing Machine. (Engineer, 1935, vol. 159, Mar. 22, pp. 308–309). The machine is a small horizontal hand-loaded testing device; made of girder section brass, it weighs but 70 lb. The test-piece is held between grips in shackles carried by two draw-bars of square section. One bar is operated by means of a capstan head, and the load is transmitted to the other draw-bar, where it compresses a spring and operates a gauge from which the load may be read. A micrometer clock gauge is attached to the drawbars to register the strain; there is also an attachment for autographic recording. Jigs and shackles are provided suitable for tensile tests (for wire or small turned specimens), for sheet metal tests, compression, bending, cupping and Brinell tests.

Tensile Machine for 300 Tons with Alternating Load. E. Gaber. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Apr. 27, p. 528). Very brief particulars are given of a 300-ton tensile testing machine; the hydraulic straining gear is so arranged that fluctuating stresses can be applied.

Photographic-Recording Micromachines for the Mechanical Testing of Metals. P. Chevenard. (Académie des Sciences, Dec. 10, 1934: Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1935, vol. 134, Jan., pp. 59–73: Métaux, 1935, vol. 10, Feb., pp. 37–49). After pointing out the importance of the study of the mechanical properties of metals as revealed by tests on very small test-pieces, the author explains the properties of the optical lever rotatable about two rectangular axes and its application to the determination of the mechanical properties of metals. He then gives details of a micromachine and its photographic recording apparatus, in which tensile, shear and bend tests can be carried out. The specimens used range in size between 1 and 2 mm. in diam., and are generally 7 mm. in length. The author concludes by giving a number of test curves obtained with the machine to show its applicability to the investigation of the mechanical deformation of metals, crystalline anisotropy, autofrettage and the penetration of quenching, welds, the influence of low-temperature tempering on the brittleness of quenched steels, &c. The use of such small specimens can yield considerable economies in time and money.

Tension Testing of Metals—New Standard Methods. R. L. Templin. (Metal Progress, 1935, vol. 27, Feb., pp. 29–32). Certain new features in the A.S.T.M. specifications are described. These relate more particularly to the size and shape of the specimens, the speed of testing, and the introduction of a new term, "yield

strength," to correspond to the yield point in metals which do not give a proper yield. (This appears to correspond to the English " proof stress.") Some attention is also paid to the use and calibration of extensometers.

Discussion on the Use of the Tension Test for Judging the Suitability of Sheet Metals for Various Purposes. (Proceedings of the American Society for Testing Materials, 1934, vol. 34, Part I. pp. 563–570).

The Modulus of Elasticity. L. Guillet, jun. (Revue de Métallurgie, Mémoires, 1935, vol. 32, Feb., pp. 61–68). A general discussion of the elastic modulus of metals, and the influence on it of various factors such as the composition of the material, heat treatment, mechanical treatment, &c.

The Peculiar Behaviour of the Elastic Modulus of Ferromagnetic Materials. M. Kersten. (Zeitschrift für Metallkunde, 1935, vol. 27, May, pp. 97–101). The author summarises modern theoretical results regarding the influence of self-stresses on the elastic modulus, on its dependence on the extent of elongation, and on the variation of the modulus with temperature, of ferromagnetic materials, and presents a comparison of the relations derived from the theory of magnetisation curves with experimental findings regarding the peculiar behaviour of the elastic modulus.

Laws of Elastic Behaviour in Metals. M. F. Sayre. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 555–561). This report summarises the results of an experimental programme undertaken by the A.S.M.E. Special Research Committee on Mechanical Springs. Certain factors which are believed to affect the elastic behaviour of steel springs are discussed.

Model to Demonstrate the Phenomena in Loaded Materials. W. Späth. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Mar., pp. 405–416). On the basis of the similarity of the load/deformation curves for periodically-loaded materials to the efficiency curves for working machines, a model has been developed to demonstrate the phenomena taking place in loaded materials. Springs are stretched between the two points of application of force ; at their mid-points they are bent, and are held apart by friction pieces. By means of this model the author explains the experimentally-determined relationships between the load and the deformation under static and dynamic loading. Under load, transverse slip must take place, on which the elastic limit, the yield point and the limit of proportionality depend very largely.

The Bend Test, and its Value as a Guide to Ductility. L. W. Schuster. (Institution of Mechanical Engineers, Mar. 29, 1935 : Engineering, 1935, vol. 139, Apr. 5, pp. 372–374 ; Apr. 12, pp. 400–402). The author discusses the technical interpretation of

a bend test and the factors which affect bending on supports by means of a former, bending on a mandrel, bending by pressing the specimen into soft metal (using a former), and bending by the application of a pure bending moment. Bend-tests of fusion-welded joints are also referred to.

Slow Bending Tests on Large Notched Bars. J. G. Docherty. (Engineering, 1935, vol. 139, Feb. 22, pp. 211–213). Notched-bar tests carried out on geometrically similar specimens are not strictly comparable; large test-pieces are less ductile, and more likely to fail than small specimens. The author tested large and small specimens under slow bending on a standard machine; the test-pieces varied in size from 100 mm. × 25 mm. to 10 mm. × 2·5 mm.; in each case the maximum stress withstood was approximately the same, but otherwise the stress/deflection curves were very dissimilar. When specimens of square section (from 10 × 10 mm. to 100 × 100 mm. section) were tested, both the breaking stresses and the curves obtained were different. The smallest specimens failed gradually; the others suddenly fractured. This was also observed in the rectangular specimens.

The Bending Tensile Test. A New Technological Method for Testing Materials. E. Buschmann. (Zeitschrift für Metallkunde, 1934, vol. 26, Dec., pp. 274–279). A specimen of sheet or wire is bent backwards and forwards while under tensile stress and the load is raised from zero to the breaking value; the elongations corresponding to the various loads are determined, and a curve is drawn. A noticeable break occurs in the curve at a certain tensile load, which appears to represent the true fatigue strength. The author describes the apparatus used, and records his experiments on non-ferrous alloys and mild steel.

Impact and Static Tensile Properties of Bolts. H. L. Whittemore, G. W. Nusbaum, and E. O. Seaquist. (Bureau of Standards Journal of Research, 1935, vol. 14, Feb., pp. 139–188). The authors describe an investigation on the impact and tensile properties of bolts. The threads used were American National coarse, American National fine, and Dardelet. Specimens were turned from bars and tested in a Charpy machine and in a tensile testing machine; the materials used were cold-rolled steel, chromium-nickel steel and some non-ferrous alloys. The impact work and static work were computed in each case. Over one-quarter of the cold-rolled steel bolts with American National threads yielded brittle failures under impact; the Dardelet threaded bolts were superior in this respect. With the ferrous materials the behaviour of the fine-threaded and Dardelet threaded bolts was approximately the same under both impact and tension; bolts with American National coarse threads gave definitely inferior results.

Relation of Impact and Tension Tests of Steel. H. C. Mann.

(Metal Progress, 1935, vol. 27, Mar., pp. 36–41). It is pointed out that in order to correlate data obtained from impact and tensile tests the same form of specimen should be used. This means that a tension impact machine is necessary. The energy absorbed may be computed in each case. (The work done is partly dissipated as heat and partly used up in deforming the specimen.) Except in the case of stainless steels, there is good agreement between the results of static and dynamic tests. With the stainless steels the velocity of impact has a marked effect. The author considers that tension impact tests may be of great value.

Researches in Impact Testing. H. Hallam and R. V. Southwell. (British Association, 1934: Engineering, 1934, vol. 138, Dec. 21, pp. 689–690; Dec. 28, pp. 703–704). In order to improve the technique of impact testing, a special ballistic machine was devised by the authors. In this machine both striker and anvil are suspended by wire, and an ingenious form of striker release is adopted. The specimen is subjected to four-point loading at impact. In tests carried out on material liable to temper-brittleness the notch-brittleness was readily detected. Age-embrittlement in certain steels was also satisfactorily revealed. Curves are plotted relating the area of fracture to the energy of fracture; the curves are found to follow a logarithmic law. As a check, static tests were made, and the curves obtained are seen to be of the same type. The authors draw no definite conclusions from their results.

Irregular Impact Figures. R. H. Greaves. (Metallurgist, 1935, vol. 10, Feb. 22, pp. 2–3). It sometimes happens that adjacent specimens of the same steel (or adjacent notches in the same test-piece) show a large variation in notched-bar impact figure. This has been attributed, from time to time, either to gross lack of homogeneity in the material or to unavoidable variation in the radius of the notch, differences in microstructure of the material at the root of the notch, or irregular energy losses arising from the design of the testing machine. Within certain ranges of tensile strength or (for a given tensile strength) at certain sizes of section treated, the conditions are present in nearly every steel for the occurrence of irregular or scattered values of the impact figure. In the breaking of an impact test-piece two modes of fracture may be involved: (*a*) Failure by shear with considerable deformation; and (*b*) failure by separation under three dimensional tensile stress with little or no deformation. The change over from one type of fracture to the other with changing conditions of material (composition, tensile strength, tempering temperature, mass treated, &c.) or of test (form of notch, test-piece, speed of impact, temperature, &c.) is not perfectly sudden, and the possibility of the occurrence of each

form of failure persists over a certain range. Irregular impact figures do not necessarily indicate any appreciable lack of homogeneity in the material, but are consequent on the operation, to various degrees, of the alternative possible modes of failure of the material under test. Over a certain critical range of conditions very slight accidental differences are sufficient to turn the balance in favour of one or other of these modes of failure with an exaggerated effect on the energy absorbed.

The Allowable Working Stresses Under Impact. N. N. Davidenkoff. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 97–102). The author describes some experimental methods of evaluating the impact strength, including a device which makes use of a piezo-electric crystal and cathode ray oscillograph. He also considers the problem of impact brittleness. It is concluded that the yield point and tensile strength of a material under impact are always higher than in static tests, but that the working conditions are less favourable; hence the same allowable working stresses should be employed for impact and static conditions. The notched-bar test is of use as a check test, but has no value for determining the allowable stresses.

Influence of the Impurities Contained in Commercial Iron on the Notch Toughness. G. Schmidt. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Dec., pp. 263–267). By special treatment with slags in a carbon-tube resistance furnace and by remelting in a high-frequency vacuum furnace a very pure material was prepared from Armco iron; to this product various quantities of carbon, phosphorus, sulphur, oxygen and nitrogen were added, and the influence of these impurities on the notch toughness of the metal was determined. In the normalised condition the steep drop in the notch-toughness/temperature curve was generally shifted towards higher temperatures by increasing contents of these elements and the maximum toughness fell to lower values; the effect was greatest for nitrogen, less for oxygen and phosphorus and least for sulphur. The change in the steep drop of the notch-toughness/temperature curve and in the maximum notch toughness due to cold deformation and artificial ageing was greatest in those steels which contained certain amounts of oxygen and sulphur together; from this it would appear that these two elements are the cause of mechanical ageing. Carbon and nitrogen, and also phosphorus in small quantities, do not enter into this effect.

The Effect of Fluid Pressure on the Permanent Deformation of Metals by Shear. G. Cook. (The Institution of Civil Engineers, 1934, Selected Engineering Papers, No. 170). The object of this investigation was to examine the effect of high external pressure on the plastic flow of metals, and to relate the results to the

various hypotheses which have been advanced. The specimens used consisted of small helices of mild steel and copper, in the annealed state. These coils were suspended inside a pressure cylinder, and lead weights were attached to the free ends. It was possible to apply a hydrostatic pressure of 2,500 atm. The specimens were tested at this pressure and at atmospheric pressure, and load-extension curves were plotted in each case. The author examines the results so obtained and indicates the inferences to be drawn.

Experimental Study of the Viscous Deformation of Wires of Iron and Nickel. P. Chevenard. (Revue de Métallurgie, Mémoires, 1934, vol. 31, Nov., pp. 473–486 ; Dec., pp. 517–535). After an introductory section of a general character the author describes raised-temperature tests made on wires of iron and nickel in various conditions of heat treatment, &c. The Coulomb modulus and internal friction were measured in an oscillometer in which the wire specimen could be maintained at any desired temperature. In an isothermal viscosimeter, the slow elongation of the wire under the influence of a load while maintained at raised temperature was measured. In another test the heated specimen was pulled against the action of a spring, and then left ; in the course of time the wire " relaxed " and the tension of the spring decreased and was recorded autographically. In a fourth test the wire was loaded with a constant weight and the temperature was raised ; the elongation of the wire was recorded as a function of the temperature. In the next section the author discusses the significance of the characteristics measured, and in the last section (the whole of the second instalment) he records the results obtained in the form of graphs and discusses them in detail.

The Dependence of the Commencement of Flow on the Stress Distribution and the Material. E. Siebel and H. F. Vieregge. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1934, vol. 16, No. 21, pp. 225–239). By tensile, bending, torsion and external-pressure tests, the authors have demonstrated that a non-uniform stress distribution raises the upper yield point to an extent which increases as the amount by which the local stress peaks exceed the average stress increases. The effect is more striking in soft than in hard steel. A raising of the yield point could still be observed after the commencement of the first flow in the elastically-stressed range under the influence of the distribution of the stresses. Changes in the stress distribution do not set up the same alterations in the upper yield points of different materials ; on the other hand, only small differences can be observed between the lower yield points determined in the fully plastic condition. As it appears to be impossible to draw conclusions of universal applicability regarding the effect of non-

uniform stress distribution on the upper yield point, there are difficulties in the way of designing statically stressed structures on the basis of the commencement of flow ; for this reason the authors recommend that the dimensions should be so selected that the load remains, with a sufficient degree of surety, below that at which the fully plastic state is reached in the most highly stressed part of the structure.

Dynamic Strength of Machine Parts Affected by Quality of Surface. A. V. De Forest. (Society of Automotive Engineers : Iron Age, 1935, vol. 135, Feb. 21, pp. 18–22). The author points out the important influence of surface defects in machine parts subject to dynamic stresses and describes the Magnaflux test for the detection of surface imperfections.

Self-Stresses in Roller-Polished Steel Rods. H. Bühler. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, May, pp. 515–516). Rods of steel St.37, 50 mm. in diam., and of steel St.42, 72 mm. in diam., were annealed and furnace-cooled in order to release any possible internal stresses ; the wire was then turned and ground. They were next submitted to a roller-polishing process, and finally the self-stresses set up were investigated by Sachs' boring-out method. The stress distributions longitudinally, tangentially and radially are recorded in diagrams. The polishing process set up high internal compressive stresses in the marginal metal, the magnitude of which increased as the extent of the reduction of the diameters of the rods during polishing was increased. For the same reduction of section polishing with one roller or with three set up practically similar self-stress conditions. As, particularly for large diameters, only the outermost marginal layers are deformed plastically, only very weak tensile stresses are left in the core, even after heavy roller polishing. However, in all cases compressive stresses of considerable magnitude were developed in the surface, which, according to earlier researches, have a beneficial effect on the alternating bend strength.

Plastic Deformation at a Hole in Steel and Magnesium Alloy Plates. R. H. Heyer and R. H. Burns. (Metals and Alloys, 1934, vol. 5, Dec., pp. 284–287). Deformation tests were carried out on specimens of mild steel and magnesium alloy plate pierced by a hole. In each case the net section was stressed beyond the yield limit ; from the results obtained concentration factors were derived. Plastic deformation was found to be greater in the steel than in the magnesium alloy.

Determination of Initial Stresses by Measuring the Deformations Around Drilled Holes. J. Mathar. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 249–254). In order to determine the initial stresses in cast, rolled, and fabricated structures, recourse has hitherto been had to the use of specially shaped pieces. In this paper a method of estimating

these stresses by the use of drilled holes is described. Such holes become elliptical if stresses are present, and an extensometer enables the stresses to be calculated. The method may be applied to the determination of stresses in rolled sections, forgings, castings, welded and fabricated work ; examples of such applications are furnished.

Stress Concentration Produced by Holes and Notches. A. M. Wahl and R. Beeuwkes, jun. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 617–623). Stress concentrations for flat specimens pierced by holes of varying sizes (compared with the width of the specimen) were determined by photo-elastic methods and by strain measurements, special precautions being taken to eliminate edge effect. Notched plates were also tested. The results obtained agree well with those derived from theory, and it was possible to establish empirical equations for use in design calculation.

The Effect of Openings in Pressure Vessels. J. H. Taylor and E. O. Waters. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 119–132). Little information appears to be available concerning the effect of openings in pressure vessels. To remedy this omission the authors carried out tests on pressure vessels provided with (*a*) unreinforced openings, (*b*) openings reinforced by nozzles riveted on, and (*c*) openings strengthened by nozzles welded on. Stress concentrations were recorded in each case. The tests indicate that all holes above a minimum diameter require reinforcing, since the stress concentration becomes more severe than that due to a hole in a flat plate, as the diameter increases ; that the reinforcement should be attached as near to the edge of the hole as is practicable ; and that there is a danger of excessive stiffening when large strengthening pads are used.

Concerning the Effect of Notches and Laws of Similitude in Material Testing. A. Nadai and C. W. MacGregor. (Proceedings of the American Society for Testing Materials, 1934, vol. 34, Part II. pp. 216–228). In a number of recent investigations on the various effects of stress concentrations produced by notches, size effects and other discrepancies were observed. Some of these cases are briefly analysed and an attempt is made to include in the comparison factors such as the speed of deformation, and geometrical and mechanical similitude. The results of tests carried out on notched bars of steel and aluminium, in which the influence of the speed of plastic deformation was considered, and photo-elastic studies of notched bars are reported.

Measurement of Self-Stresses by F. Stäblein's Method. E. Gerold. (Stahl und Eisen, 1934, vol. 54, Dec. 27, pp. 1336–1337). Stäblein's method of determining the self-stresses in steel bars quenched on one side consists in planing down one side of the

bar and measuring the curvature of the remaining piece set up by the disturbance of the stress equilibrium ; from the curvature, the stress distribution is calculated. On applying this test to 8-mm. thick strips cut out of a drawn round bar 48 mm. in diam., the author found that the calculated stress distribution across the test-piece was not symmetrical, although the treatment of the original material had been uniform. He discusses the possible causes which might give rise to such erroneous results and records the outcome of variations of the test intended to bring the results more into line with theoretical expectations.

Studies in Photo-Elastic Stress Determination. E. E. Weibel. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 637–649). This paper comprises three studies in photo-elastic technique. In the first a method of measuring strain creep in bakelite and phenolite models is described ; it is concluded that the departure from Hooke's law is likely to be very small, and may therefore be neglected. The second study deals with stress-concentration factors for tension and bending members, the shape of the specimens (including the fillet radius) being varied. The monochromatic fringe-photograph method was adopted, again using bakelite specimens. In the third series of experiments use was made of the properties of soap films acting as membranes, in order that the principal stresses might be deduced.

Practical Applications of the X-Ray Reflection Method for the Measurement of Elastic Stresses. H. Möller. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Nov., pp. 213–217). By means of various examples, the author shows that the X-ray reflection method offers a simple means of making actual non-destructive stress measurements even in finished articles. It is particularly valuable that in this way irreproachable absolute values of the stresses can be determined, in which respect the X-ray method is superior to all others. A disadvantage is, however, that only the sum of the two principal stresses in the surface can be measured.

The Overstraining of Mild Steel. J. Muir. (Journal of the Royal Technical College, Glasgow, 1935, vol. 3, Jan., pp. 372–384). A résumé is given of earlier work which explains the yielding of mild steel under bending, torsion, or hydraulic pressure in thick-walled cylinders, by the formation of narrow wedge-shaped veins of overstrained material, which spread from the fibres under greatest shear stress. Experiments are described in which a Hounsfield tensometer was used to test, in tension, small specimens cut transversely to the axis of large steel bars previously overstrained in tension by a 100-ton testing machine. No yield points were obtained with the transverse tests but only gradual departure from Hooke's law from about the original yield-point

stress. This, and the nature of the fractures obtained in the transverse tests, are explained by regarding mild steel overstrained by tension as consisting of a mixture of overstrained material and material in its original elastic condition.

Some Causes of Overstresses in the Plates of Boilers. P. Rodhain. (Annales des Mines, 1934, Series 13, vol. 6, No. 9, pp. 171–211). The author first gives some details regarding the explosion of two locomotive boilers and the features observed on subsequent examination ; the accidents had points of similarity in that both engines had been standing for some time with banked fires, both boilers exploded about ten minutes after cold feed-water had been introduced, and in both cases the initial rupture occurred along the horizontal riveted joint of the middle section of the boiler below the point of entry of the water. The primary cause must have been the incidence of overstresses in the plate. The author first discusses mathematically the strength of the riveted lap joints themselves, and concludes that they played no part in the explosions. He then deals with the effect of the introduction of the cold feed-water ; he shows that the movement of the water in the boilers was probably so slow at the time that large pockets of cold water were able to remain in contact with the boiler shell and cool it completely before they were carried away or dispersed in the rest of the boiler water, and that this local cooling of the boiler plate could set up overstresses of sufficient magnitude to lead to fissuration and ultimate rupture. The means of preventing a repetition of such disasters is to introduce the feed-water into the middle of the boiler water, well away from the shell and tubes, to subdivide the inflowing water so that large pockets of cold water do not form, and to avoid refilling the boiler when the fire is banked.

Stresses in the Plates of Boiler Shells. A. Lieberherr. (Chaleur et Industrie, 1934, vol. 15, Oct., pp. 269–274). The author presents a mathematical consideration of the stresses in boiler plate set up by expanding-in the tubes, the concentration of edge stresses due to internal pressure, and the superposition of the stresses due to beading the tube end and those due to the internal pressure.

Plasticity and Rupture of Steels in the Hot State. M. de Lacombe. (Chimie et Industrie, 1935, vol. 33, Apr., pp. 793–799). Modern steel metallurgy has led to the production of alloys diverging more and more from the carbon steels and containing large proportions of elements such as chromium, nickel, tungsten, cobalt, &c. The industrial manufacture of these steels encounters various difficulties, such as, for example, hot cracks. In the present paper, the author studies the structures of special steels and their modification resulting from variations of temperature ; he passes rapidly in review the various types of defects which

may occur in these steels, and makes suggestions regarding the direction in which remedies should be sought.

An Experimental Investigation of Cracking in Mild-Steel Plates and Welded Seams. E. G. Coker and B. P. Haigh. (Institution of Naval Architects, Apr. 12, 1935 : Engineering, 1935, vol. 139, May 3, pp. 476–478). A special form of notched plate was tested in tension, and its behaviour investigated. In order to determine the stress distribution in the elastic range a transparent model was subjected to stress analysis by polarised light. Beyond the elastic range the steel test-piece itself developed Lüder's lines, and plastic strain became general ; a yield point was recognised. The specimen subsequently continued to deform, and small cracks appeared at the root of the notch. These joined, and the main crack extended until failure occurred. Several of the steel notched discs were tested, some of which were welded. Certain of the electrically-welded samples were found to be as ductile as mild-steel plate ; this ductility was associated with high strength.

Precipitation Hardening. P. D. Merica. (Metal Progress, 1935, vol. 27, Jan., pp. 31–35, 60). The phenomenon of precipitation hardening is briefly treated, and the theories which have been advanced in explanation of age-hardening are recounted. Examples of age-hardening alloys are furnished.

Magnetic Investigation of Precipitation-Hardenable Iron-Nickel Alloys. F. Preisach. (Zeitschrift für Physik, 1935, vol. 93, pp. 245–268). The experiments were made on two alloys, one containing nickel 55, iron 45 and beryllium 0·5 per cent., and the other nickel 38, iron 46, copper 15 and manganese 1 per cent. The measurements made were concerned with changes of the coercive force, remanence, initial permeability, hardness and electrical resistance after tempering at various temperatures and for different times, after quenching and also after quenching and cold-deformation.

The Practical Differentiation between Precipitation Hardening and Martensitic Hardening. F. Sauerwald and H. Gross. (Zeitschrift für anorganische und allgemeine Chemie, 1934, vol. 221, pp. 159–160). Investigation of the phenomena during the hardening of chromium-carbon-iron alloys showed that the increase of hardness set in first between 200° and 300° C.; it must therefore be attributed to martensite hardening and not to precipitation hardening. Martensite hardening can, however, be favoured by the precipitation of crystals containing chromium resulting from treatment at higher temperatures.

Solubility of Nitrogen in Liquid Iron. J. Chipman and D. W. Murphy. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 591). The authors have devised a simple method for determining the solubility of

nitrogen in liquid iron. The method consisted in melting a charge of iron in a closed induction furnace under an atmosphere of nitrogen, holding the melt at constant temperature until absorption was complete, then cooling and analysing the resulting ingot. The solubility, at approximately 740 mm. pressure, was found to be 0·039 per cent. just above the melting point and 0·042 per cent. at 1,760° C. Within the limits of experimental error, the solubility is not affected by 0·15 per cent. of aluminium or by 0·70 per cent. of silicon. The rate of solution of nitrogen in liquid iron is not greatly affected by temperature. The presence of aluminium or silicon in the melt exerts a very great influence upon the rate of solution, the rate coefficient being increased tenfold to twentyfold in two experiments in which these elements were present.

Solubility of Copper in Iron, and Lattice Changes during Ageing. J. T. Norton. (American Institute of Mining and Metallurgical Engineers, 1934, Technical Publication No. 586). The author has redetermined the solubility of copper in iron, using X-ray methods, and puts forward a theory of age-hardening. A series of iron-copper alloys was quenched from the eutectoid temperature and the lattice parameters were measured, thus giving a curve relating the composition and parameter. The maximum solubility of copper in iron is indicated to be about 1·4 per cent. by weight. Ageing experiments were undertaken to correlate the changes in lattice parameter with the changes in age-hardness. It was found that the maximum hardness occurs when about 20 per cent. of the available copper has been precipitated. The author suggests that the initial ageing effect is due to the formation of groups or "knots" of copper atoms, and that precipitation hardening subsequently sets in, the total effect being the sum of these two.

The Effect of Deoxidation on the Ageing of Mild Steels. C. H. Herty, jun., and B. N. Daniloff. (Mining and Metallurgical Investigations, 1934, Co-operative Bulletin No. 66). The authors commence by reviewing the literature on the subject of ageing in steel, and then consider briefly the variables in furnace operation which account for the differences between steels having similar analyses. Details are furnished of experiments with four types of steel: Rimming steel; semi-killed steel; silicon-killed steel; aluminium-killed steel. Low-carbon steels were used. Specimens were quenched from 700° C. and allowed to age; the quench hardness was measured. Other specimens were subjected to stress, and the strain-ageing effect was measured. Rimming steels were seen to be highly susceptible to quench-ageing; silicon-killed steels were less susceptible, whilst aluminium-killed steels were scarcely affected. Ageing tends to decrease with increased carbon content. Rimmed, semi-killed and silicon-killed steels

were found to be very susceptible to strain-ageing; aluminium steels were much less affected.

Influence of Nitrogen and Oxygen on the Mechanical Ageing of Steel. W. Eilender, H. Cornelius and H. Knüppel. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, May, pp. 507–509). The authors present the results of tests, made on a series of very pure steels containing from 0·005 to 0·17 per cent. of carbon, to determine the influence of nitrogen and oxygen on the notch-toughness in the normalised and in the aged condition. It was found that nitrogen raised the sensitivity of the steels to mechanical ageing; and that increasing the carbon while maintaining the nitrogen content constant, decreased it slightly. Oxygen had no influence on the mechanical ageing of mild steel.

Ageing Embrittlement of 4 to 6 per cent. Chromium Steel. H. W. Wilten and E. S. Dixon. (Proceedings of the American Society for Testing Materials, 1934, vol. 34, Part II. pp. 59–79). Low-carbon steel containing from 4 to 6 per cent. of chromium is being extensively used in oil refineries in the form of heater tubes. Steel of this type is subject to embrittlement after exposure to the operating temperature of 480° C. The cracking of the tubes, during removal of the coke deposit, was found to be due to shock stresses on embrittled tubes. The authors have investigated the nature of this embrittlement and found that it is similar to duralumin-type ageing, when the ageing is carried out at room temperature. The authors are of the opinion that ageing of this type of steel is not due to actual precipitation of some element, and evidence is presented to support this view. It is also postulated that this type of ageing is similar to temper-brittleness, where loss of impact occurs without the corresponding considerable increase in hardness and tensile strength commonly associated with ageing of the precipitation type.

Machine for Measuring Hardness. Eugène. (French Association for Testing Materials, June 8, 1934: Revue de Métallurgie, Mémoires, 1934, vol. 31, Nov., pp. 507–513). The machine described and illustrated is capable of measuring the hardness of thick or very thin objects or of deposits in very thin layers. A diamond indentor is used, and the load is applied by means of a balanced steelyard carrying weights at the end and also a jockey weight. The indentation is measured by an arrangement on the principle of the optical lever which indicates the extent of movement of the part carrying the indentor. The indentations may be as small as 0·1 mm. The author gives curves showing the relation of the theoretical to the actual depth of indentation. He also presents the results of an investigation of the hardness of small specimens of carburised steel as a function of the depth of penetration of the cementation, in which this machine and also a Rockwell machine were used.

New Machine for Testing the Hardness of Metals. R. Guillery. (Revue de Métallurgie, Mémoires, 1935, vol. 32, Feb., pp. 49–53). A description of the machine, accompanied by photographs and diagrams, is given. The hardness is determined, not by measuring the diameter of the ball impression, but by calculation from the difference between the depths of penetration of the ball under two different loads.

Comparison of Brinell and Scratch Hardness. E. Scheil and W. Tonn. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Dec., pp. 259–262). In the case of homogeneous metals and alloys there is a clear relation between the Brinell hardness and the scratch hardness (determined in these experiments with a Martens machine). By deformation, precipitation hardening and the formation of a martensitic structure in low-carbon iron alloys only the Brinell hardness is raised and not the scratch hardness. In quenched carbon steel a special form of hardness increase takes place, which gives rise to very high values for the scratch hardness. There is no simple relation between the increase of hardness and the expansion of the lattice of martensite due to embedded (interstitial) carbon.

Hardness Conversions for Carbon and Alloy Steels. J. H. Hruska. (Iron Age, 1935, vol. 135, Apr. 18, pp. 20, 21, 90, 92, 94, 96). The author presents a comparative study of the various methods of determining hardness. He discusses the degree of correlation between results given by static and dynamic methods, and the lack of agreement between values obtained by the Shore scleroscope and other instruments. A conversion table of various hardness numerals is included.

Brittleness in Steel. C. L. Shapiro. (Iron Age, 1935, vol. 135. Feb. 21, pp. 12–17 ; Feb. 28, pp. 26–29, 73 ; Mar. 14, pp. 21–25, 76). Four temperature ranges of brittleness are distinguished. These are (1) carbide brittleness, (2) blue-brittleness, (3) recrystallisation brittleness, and (4) transformation shortness. To investigate brittleness a torsion testing machine was devised which allowed the specimens to be subjected to known temperatures. A number of steels, differently heat-treated, were tested. In the blue-heat range Armco iron was observed to fail in steps ; this may be attributed to precipitation and cold-work. The stepping effect appears to be due to the presence of ferrite—stepping is less in the higher carbon steels. Secondary brittleness, due to recrystallisation, may be explained on the basis of crystal size and the composition of the metal. A fine grain tends to restrict the brittleness range but increase its effect ; a coarse grain has an opposite tendency. Alloying elements influence the recrystallisation temperature and hence the secondary brittleness range. When steel is worked at its transformation temperature it suffers a loss in ductility ; this is transformation brittleness, and it is

a consequence of the allotropic change. It is not the same as red-shortness, but may be associated with it. Transformation brittleness may be controlled by the grain size and the alloying elements. On theoretical grounds a brittleness range is to be expected at the A_0 point, and carbide brittleness may, in fact, be detected. Austenitic steels are found to exhibit the stepping effect when tested under torsion. The factors which may give rise to brittleness in such steels are transformation, precipitation and recrystallisation, pseudo blue-brittleness and secondary brittleness.

Brittleness in Ductile Engineering Structural Materials. W. E. Lewis. (Institution of Engineers and Shipbuilders in Scotland: Metallurgia, 1935, vol. 11, Apr., pp. 147–148, 150). The author suggests explanations of causes of brittleness in normally ductile materials such as cast or hot-worked mild steel.

Initial Wear. H. Shaw. (Machinery (Lond.), 1934, vol. 45, Dec. 20, pp. 427–431). The author deals with the initial wear of machine parts and discusses the influence of surface finish. The use of colloidal graphite lubricant is also discussed and it is shown that with the use of this compound in the oil the initial wear of parts can be reduced to about one-sixth to one-eighth of what it would be without the use of colloidal graphite.

The Wear of Metallic Materials by Frictional Oxidation. The Question of the Origin of Fatigue Fractures. M. Fink and U. Hoffmann. (Metallwirtschaft, 1934, vol. 13, pp. 623–625). The dust produced by wear during rolling friction with slip between steel and pure iron, pure copper or nickel in the ordinary air, in liquid air or under oil, always contains oxides. *In vacuo* or in pure nitrogen, on the contrary, the rubbing surfaces remain clean and the coefficient of friction is small. The wear is therefore not a purely mechanical process but a mechanico-chemical one; the deformation imparts enhanced reactivity to the atoms in the lattice structure, so that they combine in the cold with oxygen at the surface. For the same reason, the fatigue strength of metals is raised decidedly by preventing the access of oxygen (for instance, lead test-pieces in acetic acid). Oil does not prevent friction oxidation; the addition of colloidal graphite reduces the wear but not the friction.

Contribution on the Occurrence of Frictional Oxidation. F. Roll and W. Pulewka. (Zeitschrift für anorganische und allgemeine Chemie, 1934, vol. 221, pp. 177–181). Contrary to the experiments of Fink and Hoffmann, the authors' tests, made on a wear machine of the Hanffstengel type, showed that the formation of the oxides Fe_2O_3, Fe_3O_4 and their mixtures was dependent on the temperature existing during the friction. Low Brinell hardness of the test-pieces gave rise to only slight frictional oxidation, while with higher hardness (500 Brinell) the formation of Fe_3O_4 was favoured;

with differences of hardness between the two specimens large quantities of Fe_2O_3 were formed.

Wear of Iron Alloys on Emery Paper and their Hardness. W. Tonn. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Apr., pp. 467–470). In the wear testing machine used, a disc of emery paper is fixed on a horizontal rotating disc. The specimen, measuring 5 × 5 × 25 mm., is pressed on it under a load of 1 kg. ; suitable mechanism moves the specimen radially across the disc, so that it always meets a fresh paper surface. The loss of weight of the sample after rubbing along a given spiral length of emery paper was taken as the measure of the wear. With proper precautions reproducible and comparable results were obtained. Inequalities in a particular kind of paper were demonstrable by a comparison process. Emery papers of the same grade but of different deliveries could differ markedly. The author presents the results of tests to show the influence of the carbon content on the wear, Brinell and scratch hardness of plain steels after various tempering temperatures, and also of investigations on homogeneous and heterogeneous alloy series in regard to the effects of martensitic hardening, precipitation hardening and hardening by cold deformation ; the results are clearly set out in a number of graphs. For unalloyed steels, Spindel's wear test, the emery-paper wear test, and the scratch test gave corresponding results. The relations between the wear as revealed by the emery-paper test and the structure agreed with those already found by Köster and Tonn (Archiv für das Eisenhüttenwesen, 1934, vol. 8, p. 111), using the Spindel wear test.

Special Steel Developed for Wear Resisting Service. E. F. Cone. (Steel, 1934, vol. 95, Nov. 12, pp. 49–51). Particulars are given of the physical properties of a wear-resisting steel developed by the Bethlehem Steel Co., Bethlehem, Pa. The steel is of the carbon-manganese-silicon type.

The Question of the Wear of Steel Rails. E. Cotel. (Revue de Métallurgie, Mémoires, 1935, vol. 32, Mar., pp. 137–144). The author first discusses critically the results and opinions of various authorities who have made tests to determine the wear of rails and then gives an account of his own tests, which were carried out as follows : Six cubes of basic open-hearth steel, with 0·4 to 0·9 per cent. of carbon, were tumbled for 190 hr. in separate compartments in a rotating sheet-steel drum, being thus submitted simultaneously to wear, cold-deformation and hardening. From his results the author draws the following conclusions : The wear resistance of plain steel rails (carbon, 0·4–0·9 per cent.) increases regularly with rising carbon content. In the case of normalised material, the relationships between the hardness and wear, and between the tensile strength and wear are the same. In plain steels the carbon content is the factor controlling the degree of

wear ; if the carbon can be estimated accurately, wear tests become superfluous. If the minimum wear in plain carbon steel rails is the principal requirement, a pearlitic structure will give the best results. When selecting the material for rails to be placed on steeply inclined sections of the track, or where curves are sharp and numerous, attention should be paid particularly to the capacity to work-harden, and not to the wear resistance. For track on the level and in straight sections high-carbon material is not necessary. The experience of the Hungarian State Railways shows that rails with 0·42 per cent. of carbon laid on flat ground thirty-seven years ago have worn only slightly, despite the passage of very heavy traffic.

Machinability of German and American Structural Steels. A. Wallichs. (Stahl und Eisen, 1935, vol. 55, May 30, pp. 581–585). The author reports the results of machinability tests on a series of American and German case-hardening and heat-treatable steels. No basic difference in machinability between the German and American alloy structural steels was found. The author suggests that until a short-time test is developed which will give results with a minimum of scatter, the hardness or the tensile test can be recommended as the simplest and most rapid method of gauging the machinability of the usual structural steels.

Behaviour of Automobile Constructional Steels during Machining. W. Leyensetter. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Apr. 27, pp. 517–518). The author records the results of cutting tests made under the conditions of a finishing cut, carried out on German and American steels used in the construction of automobiles.

An Apparatus for the Measurement of Roughness. D. Clayton. (Engineering, 1935, vol. 139, Mar. 29, pp. 325–327). The apparatus consists of a carriage which slides on two rods clamped to the surface under examination, and which may be moved by a micrometer at one end. A block is fixed to the carriage by a flexible steel strip ; this block has an angle piece carrying a mirror attached to the top, whilst a stylus (consisting of a piece of safety razor blade) is clamped to the bottom. A screw bearing against the angle plate enables the stylus to be lifted out of contact with the surface. The irregularities on the specimen cause the stylus to rise and fall, and the mirror to deflect. The deflection is measured by an auto-collimator ; a beam of light passes down the collimator, is reflected by the mirror, and the returning ray is received by a microscope at the other end of the collimator. A micrometer enables the deflection to be measured. The carriage is made to traverse the surface, step by step, and the corresponding irregularities are plotted to give a roughness curve. Several such curves are reproduced.

Thermal and Electrical Conductivities of Metals and Alloys. I.—Iron from 0° to 800°. R. W. Powell. (Proceedings of the Physical Society of London, 1934, vol. 46, pp. 659–679). The thermal conductivity of 99·92 per cent. iron decreases from 0·177 c.g.s. units at 0° to 0·071 c.g.s. units at 800°. The resistivity increases from $9{\cdot}6 \times 10^{-6}$ ohm-cm. at 0° to $105{\cdot}5 \times 10^{-6}$ ohm-cm. at 800°. The Lorenz function increases from $0{\cdot}62 \times 10^{-6}$ at 0° to $0{\cdot}74 \times 10^{-6}$ at 400° and then remains constant up to 700°.

Alloys of Low Thermal Expansibility. (Metallurgist, 1935, vol. 10, Feb. 22, pp. 14–16). A review of developments in the production of alloys of low expansibility, with particular reference to the work of Masumoto.

A Magnetic Dilatometer. T. C. Richards. (Iron and Steel Industry, 1935, vol. 8, Apr., pp. 261–264). In this form of dilatometer the expansion of the specimen is communicated to a pendulum, the lower end of which moves in the magnetic field across a small gap in a permanent magnet. Lateral displacement of the soft iron element within the magnetic field results in rotation. A mirror and light source enable visual or photographic records to be obtained; the magnification is high, and quite small anomalies may be detected.

An Automatic Creep Test Furnace-Guide. P. H. Clark and E. L. Robinson. (Metals and Alloys, 1935, vol. 6, Feb., pp. 46–49). A description of a creep test furnace devised for multiple specimen testing over a long period, is given. It is arranged to deal with twelve specimens of 20 in. gauge length, set vertically. The actual specimens are rods $\frac{3}{8}$ in. in diam. and 5 ft. long. Bars clamped at the gauge marks extend through the top of the furnace and enable the creep to be determined periodically. The apparatus is arranged for automatic operation; should any part fail the furnace shuts down and the failure is signalled to the operator; little supervision is required.

Elastic Behaviour in the Light of Creep and Elastic Recovery Phenomena. M. F. Sayre. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 559–561). The elastic changes which accompany a loading-unloading cycle at room temperature are re-stated, and a number of hypotheses are advanced to explain the elastic effects observed to occur when plastic flow takes place.

The Creep Strength of Steels in Relation to the Composition and Heat Treatment. P. Grün. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Nov., pp. 205–211). The tensile strength, yield point and creep strength (by a short-time test) at 400° and 500° of a number of low-alloy steels were determined. At 400° the tensile strength and yield point rose markedly with increasing carbon and chromium contents, while the creep strength increased much

less and, in fact, sank with more than 0·3 per cent. of carbon or 1 per cent. of chromium. Having regard to the cost of alloying elements, additions of silicon, manganese and copper were found to be very suitable for raising the creep strength at 400°. At 500°, as is known, molybdenum is the best alloying element; at this temperature an increase of the carbon content was practically without effect, while tungsten and vanadium, which at 400° improved the creep strength very much, were considerably inferior to molybdenum at 500°. The simultaneous addition of several elements was more effective than that of a similar amount of one element alone. In carbon, manganese, chromium and copper steels, the structure with banded pearlite produced by slow cooling gave the best creep strength; after thermal refinement the creep strength was less, which was to be attributed to the effect of the tempering action of the long heating in rendering the carbides uniform. Air-cooled molybdenum and vanadium steels had the highest creep strengths; only in the presence of higher contents of hardening elements (carbon, chromium, manganese) was the creep strength lower after quenching. Long-time loading tests up to 1,000 hr. showed that the time-extension curves did not have a uniform parabolic shape for all the steels, but the creep limit determined in short-time tests as that load under which a rate of extension of 5×10^{-4} per cent. per hr. occurs, is, nevertheless, a value that can be accepted as a basis for calculations.

Contribution on the Determination of the Creep Limit. W. Ruttmann and R. Mailänder. (Technische Mitteilungen Krupp, 1934, vol. 2, Dec., pp. 152–159). After indicating briefly the methods available for investigating creep, the authors review the modes of recording creep test results adopted by several investigators, and then present their own long-time creep test results. They conclude that the fact that the time-extension curve relating to a comparatively short and early test period is straight when drawn in double logarithmic co-ordinates is no justification for assuming that the further extension will be constant. Even on the assumption that the metal does not come to rest completely, the calculated final extension for a long loading period would be much higher than the actual value. Some of the results discussed, indeed, point to the conclusion that the materials had, in fact, come to rest within the experimental periods used. On the basis of the results of long-time tests in which the material finally reaches equilibrium, the authors conclude that the creep limit may be defined as that load under which the rate of extension during the twenty-fifth to thirty-fifth hours does not exceed 5×10^{-4} per cent. per hr., provided that the structure of the metal is stable at the temperature in question.

High-Temperature Tensile, Creep and Fatigue of Cast and

Wrought High- and Low-Carbon, 18 Cr 8 Ni Steel from Split Heats. H. C. Cross. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 533–553). This paper is a report on an investigation into the creep and fatigue properties of cast and wrought specimens of 18/8 nickel-chromium steel containing 0·067 and 0·125 per cent. of carbon. The metal was heated in induction furnaces and cast into ribbed blocks for the cast specimens and into ingots for rolling. Hence the steel was tested in the coarse-grained (as-cast) and fine-grained (rolled) conditions. Creep tests and short-time high-temperature tests were carried out, in addition to fatigue and tensile tests. Tables and micrographs are shown and the results are discussed in detail.

Compression Tests of Structural Steel at Elevated Temperatures. P. D. Sale. (Journal of Research of the National Bureau of Standards, 1934, vol. 13, Nov., pp. 713–743). Details are given of compression tests carried out on structural steel sections and round bars at temperatures up to 945° C., and of slenderness ratios between 20 and 150. Tests on cast-iron specimens were also undertaken. Two methods were used : In one the specimen was heated to a given temperature and then loaded to failure; in the other the load was maintained at a constant value and the temperature increased until failure occurred. The results are given in tabular and graphical form. It was found that strengths higher than those obtained at room temperature were developed at blue heat (about 250° C.), except in the case of slender sections and with specimens of cast iron. At higher temperatures (and with cast iron at all temperatures) the yield points disappeared. These results are held to agree with those derived from the theory of columns and from fire-tests on building columns.

Creep at Elevated Temperatures. (Metallurgist, 1935, vol. 10, Feb. 22, pp. 3–7). The results of recent research on the creep of metals at high temperatures are summarised, particular attention being paid to the work of Körber, Dustin, Ranque and Henry, and McVetty.

Creep Properties of 5 per Cent. Chromium, 0·50 per cent. Molybdenum Steel Still Tubes. H. C. Cross and E. R. Johnson. (Proceedings of the American Society for Testing Materials, 1934, vol. 34, Part II. pp. 80–104). Two steels of the 5 per cent. chromium, 0·50 per cent. molybdenum type, with carbon contents of 0·139 and 0·181 per cent. respectively, were studied to determine their creep properties. The specimens were cut from finished still tubes to represent both longitudinal and transverse sections. Five heat treatments, representing normalising and slow cooling from 845° C. and 1,150° C., were used to produce different structures and grain sizes. Hardness, impact resistance, susceptibility to temper-brittleness, and short-time tensile properties at room temperature, 540°, 595° and 650° C. were determined. The

creep properties at 595° C. for specimens slowly cooled from 845° C. and the relative creep properties at one stress at this temperature for the four other heat treatments were determined for steels of both carbon contents. Creep data at 650° C. are also included. The following conclusions are drawn: (1) An increase in carbon content materially increased the physical properties and creep resistance; (2) the longitudinal specimens showed better creep resistance than transverse specimens; (3) better creep properties were obtained for slowly-cooled specimens than for normalised specimens. Subjecting these steels to creep tests at 595° and 650° C. had little effect on the hardness, impact resistance, or tensile properties, thus indicating that the steels were quite stable at these temperatures.

The Creep Strength of Metallic Materials and its Application by the Constructor. D. W. Rudorff. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Apr. 13, pp. 453–458). A review of the results of some important investigations on creep; the difficulties encountered in evaluating and utilising the results are pointed out. Opinions regarding the mechanics of creep, the ideas and assumptions underlying "creep strength," "limiting creep stress," &c., are summarised. Examples of the use of creep values in strength calculations are given.

Qualifications of Steels for High-Temperature Service. A. E. White, C. L. Clark and R. L. Wilson. (Steel, 1934, vol. 95, Nov. 26, pp. 25–29). The authors suggest that the creep strength may, under certain conditions, be related to the proportional limit. They point out that stability of microstructure is of importance, since carbide precipitation &c., may occur; the resistance to oxidation and corrosion should also be known.

Factors Influencing Creep of Steels at Elevated Temperatures. A. E. White, C. L. Clark and R. L. Wilson. (Steel, 1934, vol. 95, Dec. 10, pp. 30–33). The authors consider that alloy steels give the maximum creep resistance when a specific amount of the alloying element is present, when the steel is in the stabilised state, and when the grain-size is favourable.

The Change of the Properties of Steel Wire on Storage at Room Temperature and in the Cold. W. Pungel, K. Lieberknecht and E. H. Schulz. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Feb., pp. 365–369). The authors describe tests made on acid and basic steel specimens with various carbon contents to determine the influence of the degree of cold-drawing and of heat treatment on the changes of the mechanical properties during natural and artificial ageing. Values for the various properties are given for temperatures of + 20°, 0° and − 20°. On storing the cold-drawn wires at room temperature, the tensile strength generally increased, but the elongation and reduction of area decreased. The type and composition of the material had no

effect ; as the degree of cold-work increased, so its effect decreased. The type of heat treatment affected only the torsion number ; it was remarkable that wires patented twice showed a greater decrease than wires patented only once. For low and medium degrees of cold-work, annealing at 250° caused greater changes than ageing, but for high degrees of cold-work the difference between their effects was small. As the testing temperature decreased (0° and – 20°) the tensile strength and elongation rose, but the reduction of area remained almost unaltered ; the influence on the bending and torsion numbers was slight. Any influence of the type of material and of the heat treatment on the strength properties at low temperatures could not be observed. Tests on the solubility of the steel wires in dilute hydrochloric acid revealed a great influence of the pre-treatment. Increasing cold-work up to 90 per cent. caused a great increase in the solubility, which, however, decreased again as the period of solution was prolonged. Annealing reduced the solubility. Longitudinal furrows after etching were attributed to defective spots in the wire rod. The splitting of isolated wires was related in part to the increase of stress brought about by the drawing process.

The Strength Properties of Materials at Low Temperatures. W. Schwinning. (Zeitschrift des Vereines deutcher Ingenieure, 1935, vol. 79, Jan. 12, pp. 35–40). The influence of low temperatures on the notch-toughness and fatigue strength of carbon steel, alloy steels and non-ferrous metals is discussed on the basis of numerous experimental results. The tensile strength, yield point and alternating bend strength of steels rise as the temperature is lowered, particularly the last-named property ; down to – 40° this applied to both smooth and notched specimens. The notch toughness decreases as the temperature is lowered ; for low-temperature work, all notch effects, sudden changes of section, &c., must be avoided, and, if necessary, heat-treated nickel steels must be employed.

Effect of Deoxidation on the Impact Strength of Carbon Steels at Low Temperatures. C. H. Herty, jun., and D. L. McBride. (Mining and Metallurgical Investigations, 1934, Co-operative Bulletin No. 67). An investigation was carried out on the impact properties of steels at low temperatures. The materials used were a rimming steel, a silicon-killed steel, a semi-killed steel, and three killed steels, all of low carbon content, and two 0·40 to 0·50 per cent. carbon steels, also well deoxidised. The steels were subjected to various heat treatments and different microstructures were obtained. Impact tests were carried out on cooled specimens, after heat treatment. The following conclusions are drawn: The low-temperature impact strength of mild carbon steels increases with decreasing oxygen content. The order of resistance to low-temperature embrittlement is : (*a*) Thoroughly killed

steels containing aluminium remaining in solution; (*b*) semi-killed steels to which aluminium has been added; (*c*) silicon-killed steels; (*d*) rimming steels. For all the steels the best heat treatment is found to be water-quenching from 875° C., followed by tempering at 675° C. Overheating tends seriously to reduce the resistance to impact.

Stress Analysis of Failures in Machine Parts. F. L. Everett. (Mechanical Engineering, 1935, vol. 57, Mar., pp. 157–161). A number of examples of the fatigue failure of machine parts in service are shown, and the cause of failure in each case is suggested.

Influence of Shape, Surface Condition and Material on the Endurance of Cast and Welded Constructional Parts. A. Thum and F. Meyercordt. (Giesserei, 1935, vol. 22, Mar. 4, pp. 90–94). On the basis of previous experiments (*see* Journ. I. and S.I., 1934, No. I. p. 586) the authors present a survey of the endurance properties of constructional elements of cast steel, welded rolled steel and grey cast iron. New tests are described in which the behaviour of high-duty grey cast iron under alternating stress, and the influence of the shape and casting skin on the endurance, were investigated. The high endurance value of thin-walled high-duty grey iron seems to point to the successful application of this material for light structures.

Influence of Chemically and Mechanically Formed Notches on Fatigue of Metals. D. J. McAdam, jun., and R. W. Clyne. (Journal of Research of the National Bureau of Standards, 1934, vol. 13, Oct., pp. 527–572). This paper considers the effect of notches on fatigue strength. The influence of pitting caused by stressless corrosion is discussed, and composite curves are derived, relating tensile strength and percentage decrease in the fatigue limit; graphs showing the effect of corrosion time are also given. The results obtained in the case of mechanically-formed notches give rise to composite curves of a similar type. The relationships between notch sensitivity and hysteresis, ductility, and work-hardening capacity are also considered. It is found that notch sensitivity depends partly on elastic hysteresis, but mainly on work-hardening capacity. High-tensile specimens are more sensitive to notching, and this may nullify the advantage of superior strength. The paper is supplemented by tables and diagrams.

Fatigue Strength and Notch-Sensitiveness of Steels at High Temperatures. W. Schwinning, M. Knoch and K. Uhlemann. (Zeitschrift des Vereines deutscher Ingenieure, 1934, vol. 78, Dec. 22, pp. 1469–1476). On specimens of ten kinds of steel (plain, low-carbon, low-alloy and special steels) the authors have determined the mechanical properties and the fatigue strength at temperatures of up to 500°, and have investigated the influence of notches on them. In all the steels examined, the yield point

decreased much more at high temperatures than did the bending fatigue strength, which actually increased up to 300°–400° in unalloyed steels. At temperatures above 300° the bending fatigue strength of plain and low-alloy steels exceeded the hot yield point. In this case tests must be made to decide which of these strength properties determines the choice of the permissible stress. In this respect, it must be noted that notch action does not decrease the yield point in plastic materials, owing to the equalisation of stress by plastic deformation, whereas it does reduce the fatigue strength very much in both cases. In all steels except the low-carbon plain steel, the notch bending fatigue strength with a deep notch, which averaged half the fatigue strength of the smooth bar, lay below the hot yield point at 400° to 500°, and also below the probable creep limit at 400°. A higher factor of safety must always be selected for fatigue than for plastic yield, because whereas a load in excess of the yield point only gives rise to plastic yield, which dies out owing to work-hardening (provided that the region of permanent flow has not been reached), a load greater than the fatigue limit always leads to fracture. Notch action is particularly important in fatigue stressing, especially in steels of high strength. That the bend fatigue and notch bend fatigue strengths of many steels increase at 300° or 400° should be neglected in design, unless the stresses are applied solely at the most suitable temperatures for the steels in question; on the other hand, the fact that the notch fatigue strength of most steels decreases at 200°, and that of high-strength steels at 400°, by 10–20 per cent., must be allowed for in calculating the permissible stresses. At 500°, the steels undergo structural changes which affect their properties differently, and no generalisations regarding the selection of permissible stress are possible.

Notch Sensitiveness of Alloyed and Unalloyed Steels under Alternating Stressing. R. Mailänder. (Stahl und Eisen, 1935, vol. 55, Jan. 10, pp. 39–41). On the basis of a large number of test results for plain steels, low-alloy manganese, silicon, nickel, chromium, nickel-chromium steels, and austenitic steels, the author has worked out the relation of the notch sensitiveness to the tensile strength, yield point and also the bending fatigue strength of the polished bar. The notch-sensitiveness is essentially dependent on the tensile strength. For equal yield-point values, the sensitiveness of the unalloyed and alloy steels, with the exception of the austenitic steels, is much the same. On comparing steels having the same fatigue strength in polished-bar form, the notch sensitiveness of the unalloyed steels is found to be slightly higher than that of the alloy steels; on the basis of equal tensile strengths the higher sensitiveness is also apparent. When the scattering of the results is considered, however, the difference between the plain and alloy steels is not so great that individual cases where a

plain steel may be less sensitive than an alloy steel cannot be found.

Fatigue Strength and Damping Capacity of Unalloyed Steels in Relation to the Chemical Composition and Heat Treatment. M. Hempel and C. H. Plock. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 2, pp. 20–31). The authors first describe the testing method employed and various factors concerned in it, and the results of static tests on a number of steels previously subjected to alternating stresses, and then deal with the influence of the carbon content on the fatigue strength and damping capacity of hypo- and hyper-eutectoid steels. A maximum value for the fatigue strength and also for the tensile strength and proof stress was found in a eutectoid steel, but no connection between the damping capacity and the carbon content was observed. Regarding the direction in which the damping altered with the period of stressing, on stressing steels containing more than 0·5 per cent. of carbon in the neighbourhood of the fatigue strength the damping decreased in all cases until a constant value was reached, but in steels with less than 0·5 per cent. of carbon the change was not clearly defined. In some materials the damping under equal loading and number of alternations of stress below the fatigue strength, and also the scatter of the damping were determined. The influence of silicon and manganese on the fatigue properties was also investigated. In two carbon steels, one nearly of eutectoid composition and the other containing but little carbon, various structures were developed by suitable heat treatment. Those structures which possessed high static strength gave high fatigue strength and low damping values. Structures of lower static strength possessed lower fatigue strength, but in these structures no relation could be found between the degree of final damping and the fatigue strength. In the eutectoid steel the damping decreased with the time of stressing for all structural conditions, but in the low-carbon steel in all structural conditions the damping changes were not uniform. In a comparison of the fatigue strengths obtained in the tensile-compression test with those derived from static tests the ratios did not agree satisfactorily.

Influence of the Size and Shape of the Test-Piece on the Torsional Fatigue Strength of Steel. R. Mailänder and W. Bauersfeld. (Technische Mitteilungen Krupp, 1934, vol. 2, Dec., pp. 143–152). After describing the torsional fatigue testing machine used, the authors record the results of their determination of the influence of the diameter of the test-piece on the torsional fatigue test results obtained; a heat-treated chromium-nickel-tungsten steel (tensile strength, 92 kg. per sq. mm.) was used. As the diameter was increased from 15 to 45 mm. so the torsional fatigue strength fell by 21 to 29 per cent.; hollow specimens suffered the least

decrease, while smooth ones and ones with transverse drilled holes showed the greatest. For thicker specimens the fatigue strength appeared to diminish further only slightly, and to approach a limiting value. These results are in agreement with values found by others for the bending fatigue strength ; nevertheless, further tests would appear necessary, particularly on test-pieces without changes of cross-sectional area in the test length, because there is here a difference from the results obtained by Peterson (*see* Journ. I. and S.I., 1932, No. II. p. 647). For the explanation of the influence of the size of the specimen the author refers to a paper by Faulhaber (*see* Journ. I. and S.I., 1933, No. II. p. 667).

The percentage reduction of the torsional fatigue strength due to variations of the cross-sectional area worked out, almost independently of the specimen size, to 38–47 per cent. for transverse holes, 35–43 per cent. for keyways and 2–15 per cent. for collars, for the particular dimensions and steel employed. These results agree, so far as comparison is possible, with the published results of similar tests.

Increasing the Durability of Structures. H. Ude. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Jan. 12, pp. 47–53.). On Nov. 17, 1934, a meeting, organised by the Materialprüfungsanstalt der Technischen Hochschule, Darmstadt, was held, at which a number of papers dealing with the durability of structures and machine parts, and means for increasing it, were presented. The present author gives a résumé of the papers under the following headings : Stresses and construction (design) ; stresses in the endurance impact test ; fatigue phenomena at points of application of forces ; raising the durability by self-stresses ; endurance tests on constructional parts (screwed joints, rolled-in boiler tubes, cast-iron constructional members, &c.) ; creep strength at raised temperatures (determination of creep strength, influence of hindrance to deformation on creep strength, &c.) ; and corrosion (intercrystalline corrosion, and corrosion-fatigue).

Fatigue Properties of Steel Wire. S. M. Shelton and W. H. Swanger. (Journal of Research of the National Bureau of Standards, 1935, vol. 14, Jan., pp. 17–32). Because of surface imperfections the fatigue limit of a structural member may be appreciably lower than the fatigue limit determined on machined and polished specimens of the same material. This is shown by the results of fatigue tests made by the rotating-beam method on galvanised heat-treated steel wire, Swedish valve-spring wire and cold-rolled mild steel wire ; the fatigue limits of specimens with the original surfaces were 40, 60 and 82 per cent., respectively, of the fatigue limits of machined and polished specimens. The development of a suitable gripping device made possible the determination of the limiting range of pulsating tensile stresses on

unmachined (in the test length) specimens of wire in the Haigh alternating-stress testing machine. The effect of the mean stress between 50,000 and 200,000 lb. per sq. in. on the limiting ranges of pulsating tensile stresses was determined on cold-drawn and galvanised, and heat-treated and galvanised, steel suspension-bridge wires, and on a high-carbon steel wire electroplated with zinc. The results showed that the limiting ranges of pulsating tensile stresses were practically independent of the mean stress within the range investigated.

Determination of the Alternating Bend Strength of Wires of Small Diameter. W. Friedmann. (Metallwirtschaft, 1935, vol. 14, Feb. 1, pp. 85–87). Illustrations and very brief particulars are given of a machine for making alternating bend tests on wires 1·5 to 3·5 mm. in diam., the ratio of length of specimen to diameter being from 17 to 25. The test results recorded all relate to non-ferrous materials.

The Effects of Heavy Oils and Greases on the Fatigue Strength of Steel Wire. R. Goodacre. (Engineering, 1935, vol. 139, May 3, pp. 457–458). An account is given of experiments conducted in order to ascertain the effect of heavy lubricants on the fatigue strength of steel wire having a carbon content of 0·55 per cent. and a limiting fatigue range (in air) of $\pm$ 23·7 tons per sq. in. It was discovered that the fatigue strength improved with increasing viscosity of the oils up to a certain limit, when there was a marked fall. The author suggests that the improvement in fatigue strength cannot be solely attributed to the exclusion of air (and hence diminution of corrosion-fatigue), and considers that the oils may have the effect of filling up the surface blemishes on the wire itself, thus delaying failure. It was also noticed that the oils improved the endurance at stresses above the fatigue limit.

The Resistance of Spring Steels to Repeated Impact Stresses. G. A. Hankins and H. R. Mills. (Iron and Steel Institute, May, 1935; this Journal, p. 165).

Fatigue in Structural Steel. B. P. Haigh. (Engineering, 1934, vol. 138, Dec. 28, pp. 698–701). Fatigue tests were carried out on a 28-30 ton mild steel and a 40-ton Chromador steel containing 0·93 per cent. chromium, and 0·31 per cent. copper. The machine used was of the electro-magnetic type with a frequency of loading of 3,000 cycles per min. Alternating stresses superimposed upon steady tensile or compressive stresses were applied. The test-pieces were turned from 1-in. plate and the "lower" yield-point (at which plastic strain continues) was determined in each case. Some specimens were also drilled with holes 0·031 in. in diam. in order to provide stress-concentration. Endurance tests were performed and the results are shown in graphical and tabular fashion. The curves are plotted so as to indicate the behaviour of the drilled and undrilled specimens. Except that the Chromador

steel is in all circumstances stronger than mild steel, the results obtained are found to be very similar.

The Breakage of Machine Parts and Means of Avoiding it. The Fatigue of Metals and Machines for Making Fatigue Tests. L. Persoz. (Génie Civil, 1935, vol. 106, Mar. 16, pp. 245–251 ; Mar. 23, pp. 274–278 ; Mar. 30, pp. 304–308 ; Apr. 6, pp. 328–330).

The Degree of Fatigue and Recovery therefrom of Carbon Steels under Repeated Impacts. F. Oshiba. (Science Reports of the Tôhoku Imperial University, 1934, vol. 23, No. 4, pp. 588–611). Experiments were carried out with circular and square impact specimens containing from 0·2 to 0·7 per cent. of carbon. The number of blows and the weight of the striker were varied, and in each case Charpy test-pieces were prepared from the fatigue-tested specimens, in order to give the " degree of fatigue." Curves were plotted to show the variation of impact value and degree of fatigue with the number of impacts. Similar experiments were carried out with specimens which were annealed after fatigue testing. The Charpy values were again obtained and the extent to which fatigue recovery had taken place was ascertained. The progress of fatigue cracking was also observed, and found to be related to the degree of fatigue.

Alternating Stressing of Tubes under Internal Pressure. A. F. Maier. (Stahl und Eisen, 1934, vol. 54, Dec. 13, pp. 1289–1291). The author presents the results of alternating stress tests made on tubes of steel and cast iron. The stress was applied by internal hydraulic (oil) pressure ; anchor bolts took up the stresses in the tube parallel to the axis, so that the metal was subjected only to circumferential stress alternations. No increase was observed in the fatigue strength in the sense of the deformation energy hypothesis, according to which, in those cases where the median principal stress is half the sum of the two external principal stresses, the flow strain (maximum principal stress difference) from the commencement of flow up to just before the inception of fracture is raised about 15 per cent. above the flow curve corresponding to uniaxial tension in the principal-stress direction in question. The circumferential stress may be regarded without serious error as determining the occurrence of fatigue fracture under internal pressure with varied median principal stress.

A Metallurgical Survey of Engineering Materials. J. W. Jones. (Journal of the Institution of Production Engineers, 1935, Jan., vol. 14, pp. 21–48). A survey of the properties and applications of the more important engineering materials, both ferrous and non-ferrous.

Recent Progress in Metallurgy. T. H. Burnham. (Wild-Barfield Heat-Treatment Journal, 1934, vol. 1, June, pp. 3–8). A review of the more important advances in metallurgy. The

author touches upon high-nickel-chromium steels, the effect of molybdenum in steel, nitriding, cutting materials, alloy cast iron, precipitation hardness, copper alloys and aluminium alloys.

Developments in Cast Steels Meet Demands of Service. A. N. Connarroe. (Steel, 1935,, vol. 96, May 13, pp. 24–28). The author refers briefly to the recrystallisation which takes place when steel is heated and cooled, and the heat treatments given to cast steel. He touches on the effects of alloying elements, and cites specifications for alloy steels and the physical properties which can be obtained from them.

Modern Steels and Weight Reduction. J. C. Whetzel. (American Iron and Steel Institute, May 23, 1935: Steel, 1935, vol. 96, May 27, pp. 40–44, 60, 61 : Iron Age, 1935, vol. 135, May 30, pp. 33–41). A general survey of the steels available for applications in which weight reduction is important is furnished. Attention is directed to the low-alloy steels suitable for this purpose, and to the corrosion-resistant alloys of the nickel-chromium and chromium-copper types. The great value of these and other high-strength steels in decreasing the dead load and increasing the pay load is stressed. Examples of typical steels and their applications are provided.

Influence of the Temperature and Rate of Deformation on the Physical Properties of Unkilled Mild Steel. P. Beintmann. (Dissertation, Hochschule Braunschweig, 1933 : Stahl und Eisen, 1935, vol. 55, Jan. 31, pp. 115–116). The author has carried out experiments to determine the influence of the temperature and rate of deformation on the mechanical properties of several mild steels, of low and higher phosphorus contents, cast in the unkilled condition. The deformation was effected by drawing with a 30 per cent. reduction in an oil bath held at various temperatures ; as a check a reduction of 40 per cent. was also applied at some temperatures. The tensile strength of the low-phosphorus steel showed a maximum at about 250°, and between 100° and 150°, at the commencement of the blue-brittle range, there was a sudden jump in the values. The higher-phosphorus steel gave similar results but at low strength values. Ageing tests showed that at temperatures above 100° deformation and ageing proceed simultaneously. It was proved that hot-tensile tests gave definite information regarding the susceptibility to ageing. To test the influence of the rate of deformation, wires were drawn at various speeds ; the amount of energy converted into heat during drawing was measured calorimetrically. In correspondence with the various temperatures produced by the different rates of drawing, the mechanical properties of the wires after ageing also varied.

Structure and Strength Properties of Large Forgings. E. Maurer and H. Gummert. (Stahl und Eisen, 1934, vol. 54, Dec. 13, pp. 1281–1289 ; Dec. 20, pp. 1309–1318). In amplification of the

work of E. Maurer and H. Korschan on 100-ton ingots (*see* Journ. I. and S.I., 1933, No. I. p. 590), the present authors have investigated the structure and mechanical properties of 45-ton casts of an unalloyed steel, a manganese, a nickel and a chromium-nickel-molybdenum steel; the three factors whose influence was studied were the composition, the degree of forging and the heat treatment. For economic reasons, the lower ends only of the ingots were stepped down by forging, the degrees of forging being in the proportion of 2 : 3 : 5. The specimens tested represented the material as forged, and after heat treatment comprising air-cooling or oil-quenching followed by tempering, they were cut from slabs constituting the cross-section after each degree of forging and representing the material from the outside to the interior. The known effects of the alloying elements on the mechanical and heat-treating properties were noticeable. Inverse ingot segregation was observed in all the steels; the alloy content had no effect on it. Fine cracks occurred in the segregated zones; they generally decreased with increasing degree of forging. In order to avoid them it was advantageous to anneal and cool slowly in the furnace after forging. The degree of forging affected only the elongation, reduction of area and notch toughness. The best ratio of the strength properties of the transverse test-pieces to those of the longitudinal ones was attained after maximum forging in the case of the chromium-nickel-molybdenum steel, but with less forging for the other steels. Longitudinal bands were seen in all the steels; with increasing forging the distance separating them clearly decreased. From the formation of the bands it appeared that with sufficiently powerful pressing (forging) and with the correct forging temperature and by the use of a swage of suitable angle, the forging effect can be made to penetrate through the core of a very large ingot. The degree of forging was without influence on the grain-size and response to heat treatment. The strength properties of only the chromium-nickel-molybdenum steel were affected somewhat by annealing at 650°–660°, the hardness due to forging being removed. The properties of all the steels were improved by air-cooling and tempering, and still more so by oil-quenching and tempering; the coarse structure was not affected, but the fine structure became more uniform and finer. Comparison with the results obtained on the 100-ton ingot showed that the mechanical properties were not dependent on the original size of the ingots. The only essential difference lay in the grain-size, which was finer in the 45-ton than in the 100-ton ingots.

Report on Strengthening Effects of Bolt Threads. H. B. Pulsifer. (Steel, 1935, vol. 96, Feb. 11, pp. 30–34). The author deals with the improvement in strength due to the presence of the thread, compared with the value calculated from the reduced

stem size. Results for plain carbon and alloy steels are tabulated.

The Determination of the Deformations and Stress Condition in Buffer Springs. H. Stark. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, June 8, pp. 727–731). For coiled springs of rectangular section, the author presents a graphic method of determining in advance the characteristics of a spring, which gives results in very good agreement with those obtained by testing the actual spring. With certain simplifying assumptions, the condition of stress in the sections of a coiled spring is given.

Rupture of a Drum of a Boiler with Curved Tubes following Overheating. G. Schneider. (Annales des Mines, 1935, Series 13, vol. 7, pp. 5–46). The author gives an account of an examination made on a Stirling type of boiler the upper front drum of which had ruptured following an overheating resulting from a shortage of water. He first gives details of the plant and describes the circumstances of the accident, and then sets out in full the results of examination, of mechanical tests on the boiler plate, and of micro- and macro-examinations. He next deals with the possibility of overheating (the heating of the drum, the water supply and the control of the water level) and concludes with a consideration of the cause of the accident and some observations of a general character. The mechanical and micrographic tests showed that the drum was made of good material, but that it had been heated for a considerable time to a temperature of the order of 900° C.

The Fracture Test as used for Tool Steel in Sweden. R. Arpi. (Metallurgia, 1935, vol. 11, Mar., pp. 123–126). A rapid and reliable test for establishing the quality of tool steel is highly desirable. In Sweden a fracture test is in use: Pieces of rolled bar are nicked to a depth of $\frac{1}{8}$ in. and heated in a muffle to various temperatures (800° C. to 900° C.) and quenched in brine. The specimens are fractured and the exposed surfaces examined. A set of standard specimens is used for the purpose of comparison. Proper care must be taken when interpreting these fractures, but the characteristics of the steel appear to be readily revealed, and the method is a valuable adjunct to the steel manufacturer.

Steels for the User.—VII. Bright and Free-Cutting Steels. R. T. Rolfe. (Iron and Steel Industry, 1935, vol. 8, May, pp. 315–318; June, pp. 341–345). It is explained that bright finished steel has many advantages—such as reduction in machining cost or wear on dies—but that care must be taken not to work-harden the material too severely. The effects of cold-work may be corrected by annealing; but if low-temperature annealing is adopted the pearlite may become divorced and the steel will be brittle. Normalising will restore the impact value and cause the pearlite to re-form. Free-cutting steels have a high machinability, and this is imparted by the use of high phosphorus or high sulphur

and manganese contents. Free-cutting steels containing high phosphorus are likely to be extremely brittle, especially if hard-drawn. The microstructure of such steels shows numerous inclusions and the presence of coalesced pearlite. The author cites cases of failures which have occurred owing to the use of these steels, mainly as a consequence of their low shock resistance. However, if the phosphorus content is reduced and the percentages of sulphur and manganese are increased, free-cutting steels with satisfactory mechanical properties may be obtained.

Breakages and Accidental Damage to Rails. J. Merklen and E. Vallot. (Génie Civil, 1934, vol. 105, Dec. 22, pp. 572–575). The authors set out and discuss various criticisms which had been levelled at their paper on this subject (*see* Journ. I. and S.I., 1934, No. I., p. 594). The matters dealt with are concerned mostly with the properties and testing of rail steel.

Locomotive Tyres. L. E. Grant. (Metals and Alloys, 1934, vol. 5, Nov., pp. 231–235 ; Dec., pp. 277–280). A discussion of the causes of tyre failures. The manufacture of tyres is also discussed. In general, there are four types of tyre failure : The snap break, which usually occurs in a thin tyre worn too near the condemning limit ; the progressive fracture, which may start in the bore or begin as a flange crack ; shelling, the only type of failure that can ordinarily be detected early enough to prevent complete failure in service, and which consists of a surface disintegration, usually in the centre of the tread ; and defects in the steel, such as pipes and internal cracks.

The Use of Ferrous Materials for Aeronautical Purposes. J. R. Handforth. (Metal Treatment, 1935, Spring Number, pp. 33–37). The author reviews the development of ferrous metals primarily intended for use in aircraft. The selection of the material is dealt with, and steels suitable for case-hardening, for springs, and for constructional work are considered. Space is devoted to a survey of the alloy steels which are available and specially suitable for aircraft work.

The Engineering Aspect of High-Strength Sheet Steels. V. H. Lawrence. (Iron Age, 1935, vol. 135, Jan. 24, pp. 28–30, 54). The factors, calculable and incalculable, which determine the suitability of high-strength sheet steels for engineering purposes are listed.

Steel Sheet Pilings of the Larsen Type of the Dortmund-Hörder Hüttenverein A.G., Dortmund. M. Ros. (Eidgenossische Material., Zurich, 1933, Bericht Nr. 70 : Zeitschrift des Vereines deutscher Ingenieure, 1934, vol. 78, Nov. 17, p. 1352). Sheet piling is subjected to very heavy stressing during pile-driving and often afterwards also. The Dortmunder Union have developed a new special steel called " Resista " for this particular purpose. The mechanical properties of two ordinary steels (37–44 and 50–60

kg. per sq. mm. tensile strength) and of the new steel are tabulated to show the superiority in every respect of Resista steel, the composition of which, however, is not given.

Wire Rope Research. Tenth Meeting of the Committee for Wire Rope Research of the V.D.I. R. Woernle. (Zeitschrift des Vereines deutscher Ingenieure, 1934, vol. 78, Dec. 29, pp. 1492–1498). The author gives a summary of the papers presented at the Tenth Meeting of this Committee of the Verein deutscher Ingenieure, which took place on July 20, 1934, under his Chairmanship. The subjects dealt with included the determination of the influence of the shape of the sheave groove, corrosion and the stiffness of the rope on its life; investigations of the internal condition of ropes in regard to wire fractures and corrosion; experiments with ropes for winding in winzes; investigations on the number of bends to break ropes in relation to the diameter of the pulley and the effect of twists on wire rope; and the problem of the tensile stressing of ropes running over sheaves with various arcs of grip.

X-Ray Investigation of Wire Ropes. R. Glocker, P. Wiest, and R. Woernle. (Stahl und Eisen, 1935, vol. 55, Jan. 3, pp. 21–22). Owing to the shape of wire rope, the thickness of metal through which the X-rays must pass is greater near the medial section than at points away from it; to even up this difference and prevent over-irradiation of the thinner sections the authors clamp on to the specimen two shaped pieces of iron which fit snugly to the wire rope and present plane parallel front and back surfaces to the X-rays; at the medial section the rope is not covered, but on either side the decreasing thickness of rope is compensated for by the increasing thickness of the attached pieces. Examples of radiographs taken in this way are reproduced.

Dynamic Stressing of Hoisting Cables. H. Herbst. (Glückauf, 1934, vol. 70, Dec. 1, pp. 1149–1154). On the basis of experiments carried out in the experimental mine shaft at Gelsenkirchen, the author discusses the principal causes of dynamic stresses in hoisting cables, namely, the brake-impacts of the hoisting engine when moving the cage at the bank, and accentuated vibration of the cable. In regard to the former, account is taken of the influence of the elastic ground rope. Regarding the latter, examples are given to show that the period of the natural vibration of hoisting cables can be accurately calculated, and that in the designing of hoisting gear the vibrations to be expected can be allowed for.

Design of Crane Hooks and Other Components of Lifting Gear. H. J. Gough, H. L. Cox, and D. G. Sopwith. (Institution of Mechanical Engineers: Iron and Coal Trades Review, 1935, vol. 130, Feb. 8, pp. 254–255). The authors report the results of an investigation of the strength of the three types of crane hooks

widely employed in works for heavy lifting. Tensile, tensile-impact, impact and fatigue tests were carried out on crane hooks, sling hooks and Liverpool hooks. It is concluded from the results of the tests that the hooks had behaved in a manner which justified confidence in the design and promised a satisfactory performance in service. A slight but general superiority of mild steel over wrought iron as the material for lifting hooks is shown; this is not, however, sufficient to render necessary the inclusion, in the specification, of any discriminating clauses in this respect.

Properties of High-Speed Steel Made in the Coreless Induction and in the Arc Furnace. R. Scherer. (Stahl und Eisen, 1935, vol. 55, Mar. 7, pp. 276–279). The author reports the results of comparative tests made on several hundred casts of high-speed steel made in 1- and 4-ton high-frequency furnaces and in the arc furnace. The carbide distribution was very similar in both types of steel, as were the cutting test results; nevertheless, the high-frequency steel was superior, in that the fracture of the hardened metal and the machining test results were better. A very high cutting efficiency could be obtained in high-frequency steel by means of special furnace operation and the use of a glass slag.

New Alloy Steels and Their Application to Car Equipment. G. N. Schramm, E. S. Taylerson, and A. F. Stuebing. (American Society of Mechanical Engineers, Dec. 4, 1934: Iron Age, 1934, vol. 134, Dec. 6, pp. 33–38).

Alloy Steels: Their Properties and Manufacture. W. H. Hatfield. (Iron and Steel Industry, 1935, vol. 8, Feb., pp. 183–186). The various types of alloy steel are reviewed, including structural and low-alloy steels, medium- and high-tensile nickel-chromium steels, nitriding steels, heat- and rust-resisting alloys, tool steels, magnet steels and other special alloys. The manufacture of alloy steels in general is briefly touched on.

Future Research on Alloy Steels. J. H. Andrew. (Metallurgia, 1934, vol. 11, Nov., pp. 1–6). The author surveys present-day knowledge of alloy steels, with special reference to their constitution, and suggests that systematic investigation be pursued. He advances hypotheses to account for the behaviour of these steels, and attempts to explain phenomena such as impact brittleness and resistance to corrosion and scaling.

Recent Developments in the Field of Special Steels. A. Fry. (Montanistische Rundschau, 1935, vol. 27, Apr. 16, Stahlbau-Technik, pp. 1–6). (*See* Journ. I. and S.I., 1934, No. II., p. 686).

Low-Alloy Nickel-Free Structural Steels. E. Houdremont and H. Kallen. (Technische Mitteilungen Krupp, 1934, vol. 2, Dec., pp. 117–126). A general account of the properties of manganese, silicon, chromium, molybdenum, tungsten and vanadium steels is followed by analyses and mechanical tests of steels of these types used for specific purposes.

Sulphur-Manganese Steels. R. Vogel. (Zeitschrift für Metallkunde, 1934, vol. 26, Nov., pp. 244–247). In recent times steels have been developed which besides possessing good strength properties are easily machinable. Their peculiar feature is that in addition to a small percentage of manganese they contain up to 0·7 per cent. of sulphur. In order to explain how this element, which is so undesirable in very small quantities, can exert a beneficial influence in larger amounts, the author gives consideration to the Fe–FeS–MnS–Mn system, and describes the development of the structure of the sulphur-manganese steels during cooling from the molten condition ; in this an important part is played by a process of separation into the individual components, which takes place during the course of the crystallisation.

Manganese Improves Resilience. B. Thomas. (Heat Treating and Forging, 1934, vol. 20, Nov., pp. 531–533). Data are presented which show that an increase of 0·14 per cent. of manganese in a 0·53 per cent. carbon steel is sufficient to improve the hardening capabilities of the material to the extent that an average increase in strength of 52 per cent. is obtained. The resilience of the steel is increased by about 63·7 per cent.

Cast Manganese Steel with Higher Strength Properties. V. Zsák. (Giesserei, 1935, vol. 22, Apr. 26, p. 195). The strength properties of heat-treated cast manganese steel (carbon 0·23, manganese 1·38, silicon 0·54, and phosphorus 0·046 per cent.) are briefly indicated. The superior economy of the acid over the basic electric furnace, in the smaller sizes, for its manufacture is mentioned. The author's purpose is to demonstrate that suitably heat-treated ordinary cast steel with higher manganese contents can compete with alloy cast steel under the conditions of average static strength requirements.

Metallurgical Applications of Silicon. J. W. Donaldson. (Metallurgia, 1934, vol. 11, Nov., pp. 20–22). This article deals with the alloys of silicon. Mention is made of silicon steel for structural and electrical work, and of silicon cast irons of acid and heat-resisting qualities. Space is also given to the non-ferrous alloys of silicon.

Steels for the User. V.—The Effect of Silicon, Sulphur and Phosphorus. R. T. Rolfe. (Iron and Steel Industry, 1935, vol. 8, Jan., pp. 127–130, 136). Reference is made to the effect of silicon in the production of killed steel, and such steel is compared with rimming steel containing little or no silicon. The effect of sulphur in inducing red-shortness in steel is examined and the influence of manganese in counteracting this is discussed. Mention is made of the free-cutting steels containing sulphur. Phosphoric steels are then dealt with, and the joint effect of sulphur and phosphorus is described ; the author's remarks are supplemented with a table.

Steels for the User.—VI. R. T. Rolfe. (Iron and Steel Industry, 1935, vol. 8, Mar., pp. 233–236). The effect of manganese is considered, both in relation to its presence as an impurity in steel, and as an alloying element. The usefulness of low manganese alloys is noted, and attention is directed to austenitic manganese steel containing 11–14 per cent. of manganese. Space is then devoted to the phenomena associated with the solidification of steel ingots, and the work of the Committee on the Heterogeneity of Steel Ingots is quoted.

Influence of Very Small Quantities of Copper and Nickel on Unalloyed Steels. H. Bennek. (Stahl und Eisen, 1935, vol. 55, Feb. 7, pp. 160–164: Technische Mitteilungen Krupp, 1934, vol. 2, Dec., pp. 129–133). The scaling, surface decarburisation and some strength properties, the tendency to red-shortness and the behaviour on quenching were determined on two series of steels, containing 0·1 and 0·9 per cent. of carbon, respectively, in which nickel (0·01–0·2 per cent.) and copper (0·1–2·0 per cent.) were present. It appears that copper and nickel contents not exceeding 0·25 per cent., such as may occur in commercial steels as unintentional impurities, have no influence on the working-up of the material, independent of the carbon content. The tensile properties and hardness in the normalised and soft-annealed conditions also suffer no appreciable alteration. Nevertheless, the hardenability is so markedly increased by such small amounts of copper and nickel as 0·04 per cent. that for certain special uses account must be taken of this effect.

Effect of Small Quantities of Copper and Nickel in Steels. (Iron and Coal Trades Review, 1935, vol. 130, Mar. 15, p. 462). An abridged English translation of the above paper by H. Bennek.

Copper Alloyed with Steel. C. H. Lorig. (Metal Progress, 1935, vol. 27, Apr., pp. 53–56, 78). The constitution of copper steels is referred to, and the effect of copper on the heat treatment, mechanical properties, and corrosion resistance is discussed. It is pointed out that the low-copper steels are used mainly on account of their resistance to corrosion, while the medium-copper steels also confer enhanced mechanical properties. The higher-copper steels are not very much used.

Heat-Treatable Copper-Alloyed Cast Steel. E. Söhnchen and E. Piwowarsky. (Giesserei, 1935, vol. 22, Mar. 1, pp. 96–100). The authors carried out their tests on two series of steels, Bessemer and electric furnace cast steel, both of which were prepared with (*a*) very little, and (*b*) nearly 1 per cent of copper, respectively. The specimens were subjected to an annealing treatment at various temperatures and of different durations. The influence of the heat treatment on the hardness, notch-toughness and magnetic properties is shown in graphs. The effect of other alloying elements on the response of steels to heat treatment is

dealt with partly on the basis of the authors' own work and partly on the researches of other investigators.

Develops New Low-Alloy, High-Strength Steel for Transportation Field. H. L. Miller. (Steel, 1935, vol. 96, Apr. 29, pp. 39–40). A steel has been developed containing 0·50 to 1·50 per cent. of copper, 0·40 to 0·80 per cent. of nickel, and up to 0·20 per cent. of molybdenum. It is stated to give good mechanical properties; it shows little tendency to air-harden, and possesses satisfactory corrosion resistance.

Nickel Alloys in Aircraft Engineering. Y. Taji. (Japan Nickel Review, 1935, vol. 3, Jan., pp. 20–90). This article is a survey of the use of nickel alloys, especially the nickel-chromium and stainless steels, in the construction of airframes and engines. Particular attention is paid to strip and sheet material and to valve steels and drop forgings.

The Influence of Beryllium in Steel. W. Kroll. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Jan. 5, pp. 28–29). The properties of beryllium and its influence when alloyed with steel are briefly reviewed.

Application of Beryllium Alloys in Clocks. W. Rohn. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Jan. 5, pp. 22–23). Reference is made to the use of nickel-molybdenum-iron alloys containing 1 per cent. of beryllium for making clock and watch springs, but the composition of the alloys is not stated.

New Rôle of Titanium in Steels and Alloys. G. F. Comstock. (Metal Progress, 1935, vol. 27, Jan., pp. 36–41). The use of titanium as a deoxidiser is mentioned, and its value in producing low-carbon steels and in inhibiting weld-decay in stainless steels is commented on. If titanium is added to 5 per cent. chromium steel it prevents air-hardening, whilst in cast iron it acts as a graphitiser. This element also refines the grain of certain ferrous and non-ferrous alloys.

Lithium. H. Osborg. (Electrochemical Society, 1934, Sept. 27–29: Metal Industry, 1934, vol. 45, Dec. 21, pp. 585–587; Dec. 28, pp. 617–618). Among other matters, the author touches on the influence of lithium on cast iron, carbon steel and stainless steels. He shows that lithium confers enhanced physical properties.

American Wrought and Cast Iron of the Civil War Period. H. M. Wilten and E. S. Dixon. (Metals and Alloys, 1935, vol. 6, Mar., pp. 63–66). An account is furnished of an examination of the remains of a boiler which formed part of a ship abandoned, half submerged, in 1863. Analyses, mechanical tests and micrographs were made; they reveal that the wrought iron of the period is only slightly inferior to the modern product, whilst the

corrosion resistance of both the wrought and cast iron is very good.

Some Observations on Sponge Iron and the Properties of the Direct Steel Made from It. R. S. Dean, E. P. Barrett, and C. Pierson. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 592). The authors describe the features of sponge iron, wrought iron obtained by briquetting sponge iron, and metal produced by melting this iron; they relate these features to the iron ore from which the sponge iron was derived. A comparison is also made between the properties of ordinary wrought iron, and iron produced from sponge iron. The cellular structure present in the ore used for producing sponge iron is found to persist, even after briquetting, melting and carburising.

Nickel Wrought Iron, A New Product. E. F. Cone. (Iron Age, 1935, vol. 135, Jan. 24, pp. 22–24). Wrought iron containing up to 3·50 per cent. of nickel is being produced on a commercial scale by the Aston process, at the plant of the A. M. Byers Co., Pittsburgh. The presence of nickel is said to increase the yield point by 50 per cent. and the tensile strength by 25 per cent. without a marked decrease in ductility. The properties of the nickel wrought iron can also be improved by suitable heat treatment.

SPECIFICATIONS.

British Standard Specification for Bull Head Railway Rails. (British Standards Institution, No. 9–1935). This specification has been revised. The revision was brought about by the demand for a rail which would give a greater length of life than the carbon rails previously specified, and with this end in view a quality having a higher percentage of manganese, to be known as a "medium manganese" rail, has been included with appropriate analyses and tensile tests. Of the qualities previously specified the "ordinary carbon" rail has been deleted; the "higher carbon" quality has been retained, with some slight adjustment to the chemical analysis.

British Standard Specification for Steel Bars for the Production of Machine Parts for General Engineering Purposes (Suitable for Automatic, Semi-Automatic and Turret Lathes). (Revised Feb. 1935). (British Standards Institution, No. 32–1935).

British Standard Specification for Wrought Iron and Mild Steel Hooks of the "C" or Liverpool Type. (British Standards Institution, No. 591–1935).

British Standard Specification for Steel Castings for General Engineering Purposes. (British Standards Institution, No. 592–1935).

British Standard Specification for Steel Sheets for Transformers for Power and Lighting. (British Standards Institution, No. 601–1935).

Tested Chain according to DIN 685. E. Kleditz. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, June 1, pp. 679–681). Brief details are given of German Standard DIN 685 covering the manufacture, testing and use of steel chain.

The Modifications Introduced into Part AI–I of the C.P.S. by the Commission for Siderurgical Products of the "A. F. Nor." Lepan-Drevdal. (Revue de Métallurgie, Mémoires, 1934, vol. 31, Nov., pp. 495–506). The Comité Supérieur de Normalisation has revised the new edition ("Compilation of 'U.F.' testing methods for siderurgical products") of the older Part AI–I adopted in 1920 by the Commission Permanente de Standardisation. In this document are collected the most important specifications regarding testing methods at present used in France for the checking and acceptance of siderurgical products. In the present article the author presents a summary and extracts from some of the specifications for the various mechanical tests.

MAGNETIC AND ELECTRICAL PROPERTIES OF IRON AND STEEL.

Magnetic Materials. W. C. Ellis and E. E. Schumacher. (Metals and Alloys, 1934, vol. 5, Dec., pp. 269–276 ; 1935, vol. 6, Jan., pp. 26–28). The authors first consider soft iron, and note that for minimum losses (maximum permeability) iron of the highest purity is required. Carbon and oxygen, especially, require to be eliminated ; silicon may be used for this purpose, giving rise to the 4 per cent. silicon steels ; alternatively, vacuum fusion may be adopted ; yet a third method is hydrogen treatment. Nickel-iron alloys yield very high permeabilities ; their properties are generally related to the heat treatment and crystal lattice. Materials for permanent magnets include chromium, tungsten and cobalt steels. Recently new ternary alloys have been developed, such as the Fe–Al–Ni alloys.

Alternating-Current Permeability and the Bridge Method of Magnetic Testing. C. E. Webb and L. H. Ford. (Journal of the Institution of Electrical Engineers, 1935, vol. 76, Feb., pp. 185–194). A method for the direct measurement of the quantities involved in the a.c. permeability of a specimen, namely, B_{max} and H_{max} is described. It is applied in an investigation of the

dependence of the a.c. permeability of commercial sheet materials on frequency and wave-shape at power and telephonic frequencies. In agreement with other observers, the effect of frequency is found to be negligible up to 500 cycles per sec., apart from a reduction, attributable to eddy currents, at magnetising forces for which the permeability is high. Tests on a range of specimens with magnetisations giving wave-shape conditions varying between sinusoidal voltage and sinusoidal current, failed to show the increased permeability with approximation to a sinusoidal current wave which was observed by Lombardi and McLachlan. Within the accuracy of the measurements, the permeability appeared independent of wave-shape between these two practical limiting conditions. In the second part of the paper a comparison between the results of loss measurements on magnetic materials by bridge and wattmeter methods is described. The discrepancies observed are shown to be entirely attributable to the errors in the bridge results due to the presence of harmonics, and the conditions under which the bridge method may be used satisfactorily for iron-testing, at both power and telephonic frequencies, are deduced.

Magnetic Methods of Testing Materials. W. Gerlach. (Zeitschrift für technische Physik, 1934, vol. 15, pp. 467–469). Methods for examining ferromagnetic materials for internal defects (for instance, welds) are based on the changes in the normal component which occur at the defective spot when the material is magnetised. For non-ferromagnetic materials a method dependent on eddy currents is used.

Some Problems on the Theory of Ferromagnetism. T. Hirone. (Science Reports of the Tôhoku Imperial University, 1934, vol. 23, No. 4, pp. 523–536). The author discusses the variation of the saturation value of magnetisation with temperature, and attempts to correlate the theoretical and experimental data obtained. Reference is made to the specific heat anomaly of a ferromagnetic substance, and the results derived from mathematical analysis and by experiment are compared.

Investigations on Magnetostriction. A. Schulze. (Metallwirtschaft, 1934, vol. 13, pp. 929–931). Summary discussion of investigations on magnetostriction in nickel, iron and cobalt.

Thermoperm, a Material of which the Magnetisability Varies with the Temperature. F. Stäblein. (Technische Mitteilungen Krupp, 1934, vol. 2, Dec., pp. 127–128). Some details are given of the magnetic properties of this special steel developed by Krupp's, but its composition is not stated. Its particular use lies in compensating the error due to temperature variations which may arise in electrical measuring instruments.

The Position of the Application of Nickel Alloys for Permanent Magnets. (Nickel-Bericht, 1935, vol. 5, pp. 1–3). The good

magnetic properties of new magnet steels containing nickel are pointed out; for permanent magnets an aluminium-nickel and a cobalt-titanium-nickel steel are particularly suitable. Their properties are compared with those of the tungsten steels and their advantages are indicated.

The Influences of Annealing on the Quenching-Hardness and Coercive Force of Tungsten Magnet Steel. G. Kojima. (Kinzoku No Kenkyu, 1935, vol. 12, Feb., pp. 79–88). Tungsten magnet steels were annealed and quenched at various temperatures and the coercive force was measured in each case. The highest coercive force was obtained by annealing at 1,000° C. and quenching from 900° C.

Properties of Nickel-Aluminium Magnet Steel. W. S. Messkin and B. E. Somin. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Jan., pp. 315–318). The authors have investigated the magnetic properties of sand-cast nickel-aluminium magnet steels, and the influence on them of variations in dimensions, composition and heat treatment. Corresponding to an optimum section (that is, best rate of cooling) maxima are obtained in the coercive force and remanence; increasing the aluminium content (between 12 and 18 per cent.) shifts the maximum in the coercive force towards greater thicknesses, but the position of the maxima in the remanence and the maximum induction are practically unaffected. The nickel content is best kept at about 25 per cent.; only when increased remanence is required can it be reduced to about 22 per cent. Deficient coercive force and remanence in thick-sectioned magnets can best be remedied by heating to 1,100° and then cooling in air; on the other hand, the properties of thin-sectioned magnets are improved by tempering at 700° for from 2 to 5 hr. Water-quenching and tempering are recommended when a coercive force of 250 to 350 oersted is required together with the highest possible remanence. As no method of heat treatment will give simultaneously the maximum values of coercive force and remanence corresponding to correct cooling conditions after casting, it is advisable to adopt from the commencement the most suitable dimensions for the castings by giving attention to the design. The influence of carbon on the magnetic properties of the nickel-aluminium steels was found to be less than had previously been believed. For the magnetisation of the magnets, a field strength of 8,000–10,000 gauss is sufficient; in the event of difficulty in this respect, magnetisation with superimposed a.c. and d.c. currents is recommended.

New Alloys for Magnets. A. B. Everest. (Metal Treatment, 1935, Spring No., pp. 43–47). The properties desirable in magnet steels are outlined, and the materials available are critically

examined ; the nickel-aluminium steels recently introduced are compared with the cobalt magnet steels.

Production, Properties, Analyses and Uses of Cobalt Magnet Steels. E. F. Cone. (Steel, 1935, vol. 96, May 13, pp. 48–49). The production of cobalt magnet steel at the works of the Bethlehem Steel Co. is described. The alloy is melted in high-frequency furnaces, poured into 4½-in. square ingots and hammered into billets which are subsequently rolled. The heat treatment of cobalt steel is given, together with some analyses.

Special Magnetic Behaviour of Cold-Rolled Iron-Nickel Alloys (Development of Isoperm). O. Dahl and J. Pfaffenberger. (Metallwirtschaft, 1935, vol. 14, Jan. 11, pp. 25–28). The authors present data showing the influence of special rolling and annealing treatments on the magnetic properties of alloys with 40 per cent. of nickel and 60 per cent. of iron. Tables show the dependence of the magnetic properties on the degree of reduction in the finishing mill for a constant reduction in the break-down mill and *vice versa*, and on the annealing temperature for constant reductions in the mill passes. Magnetisation curves are given for iron-nickel alloys with various alloy additions and after various treatments.

New Silicon Steel Commends Itself to the Electrical Industry. T. W. Lippert. (Iron Age, 1935, vol. 135, Feb. 21, pp. 23–27). Particulars are given of a silicon steel developed by N. P. Goss and the Cold Metal Process Co., Youngstown, Ohio. The steel has magnetic properties similar to those of a single crystal. Its permeability is very high and it has extremely low hysteresis losses.

CONSTITUTION, STRUCTURE, CRYSTALLOGRAPHY.

Review of Theoretical Metallurgy during 1934. R. F. Mehl. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 594). Theories of states of aggregation, allotropy, growth and properties of metal crystals, deformation, recrystallisation and grain size, crystal structure, structure of alloys, electron diffraction, transformations in alloys, age-hardening, constitution of alloy systems, thermal properties and thermodynamics, diffusion, reaction with gases and corrosion, and electrical and magnetic properties are reviewed. A bibliography of 382 references to the literature is appended.

State and Development of the Non-Destructive Testing of Materials. R. Berthold. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Apr. 20, pp. 477–484). A review of the following methods and apparatus used for the non-destructive

testing of materials: (*a*) Examination of the fine structure by X-rays (X-ray spectrograms); (*b*) magnetic methods; (*c*) iron-filings method; (*d*) magnetic-acoustic method; and (*e*) the milling test for welds.

Steel Inspection Methods and their Limitations. W. E. Jominy. (Iron Age, 1935, vol. 135, Apr. 11, pp. 8, 9, 59–63). The chief tests employed are enumerated, and discussed to some extent; a few of the special tests (for grain-size, inclusions, surface condition and so on) used in automobile plants are described.

Rapid Etching of Cementite in Steels. H. S. van Klooster and W. J. Schaefer. (Metals and Alloys, 1935, vol. 6, Mar., pp. 57–58). In an attempt to find a substitute for sodium picrate as an etching medium for cementite the authors investigated the effect of various solutions, notably those of pyrogallol in potassium hydroxide. The most effective reagent was found to be the ordinary alkaline solution such as is used for absorbing oxygen in gas analysis.

New Etching Reagent for Investigating the Macrostructure. A. Matting. (Autogene Metallbearbeitung, 1934, vol. 27, pp. 353–355). For macro-etching, the author recommends the use of a solution of 3 grm. of copper ammonium chloride in 25 c.c. of distilled water to which are added 50 c.c. of concentrated hydrochloric acid (sp. gr. 1·19) and 15 grm. of iron chloride.

Apparatus and Method for Metallographic Work at Low Temperatures. O. A. Knight. (Metals and Alloys, 1934, vol. 5, Nov., pp. 256–257). An account is given of low-temperature microscope technique. The cooling medium is liquid air or "dry ice"; care must be taken to prevent moisture from freezing on to the surface of the specimen. The cooling agent is applied to the reverse side of the specimen, which is mounted so as to form the floor of an open cylinder. Success depends on attention to detail—such as the provision of tight gaskets, and the removal of moisture from the air space between the specimen and the microscope objective. The objectives appear to withstand the cold satisfactorily.

The Electron Microscope and its Applications. B. von Borreis and E. Ruska. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Apr. 27, pp. 519–524). The basic principles and construction of the electron microscope, its advantages and applications are described and illustrated. In this apparatus the "image" is formed by beams of electrons instead of by rays of light; it is rendered visible by means of a fluorescent screen or a photographic plate.

Theory and Use of the Metallurgical Polarisation Microscope. R. W. Dayton. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 593). The theory of polarisation is dealt with, and several metallurgical applications

are discussed, notably in connection with anisotropy and the presence of inclusions in metals. Examples of the use of the polarisation microscope in distinguishing between oxide and sulphide inclusions are described, and consideration is given to the theory of the optical phenomena associated with the effects observed.

Panphot, a New Camera-Metallurgical Microscope. H. Freund. (Giesserei, 1935, vol. 22, Feb. 1, pp. 57–59). After touching on the development of the metallurgical microscope the author gives an illustrated description of a new instrument built by Leitz.

Bright-Field or Dark-Field Illumination. A Contribution to Progress in Metallography. H. Freund. (Giesserei, 1934, vol. 21, Dec. 7, pp. 521–522). The advantages of dark-field over bright-field illumination in the micro-examination of metallurgical specimens are indicated, and a dark-field illuminator is briefly described.

Metallographic Films. E. O. Bernhardt and H. J. Wiester. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Jan. 5, pp. 7–11). The authors first describe briefly the austenite-martensite transformation, and then give brief details of the technique of taking a kinematographic film of the transformation. They then touch on other applications of micro-kinematography, such as the observation of recrystallisation, grain-growth, the α–γ transformation in iron, and surface hardening. Mention is also made of " optical etching," by which is meant the observation of certain optically-anisotropic crystals (such as tin and zinc) by polarised light; under crossed nicols the crystal structure of the unetched polished surface becomes visible.

Investigations on X-Ray Fluorescent Screens. R. Berthold, N. Riehl and O. Vaupel. (Zeitschrift für Metallkunde, 1935, vol. 27, Mar., pp. 63–65). Fluorescent screens are much less used than photographic films for showing X-ray shadowgraphs, because the ability to reveal small defects is less. The authors present the results of experiments to determine whether the brightness of the screens (on which the ability to detect flaws depends) could not be increased by the use of new fluorescent materials. The determination of defects was found to improve as the grain-size of the fluorescent material and thickness of the layer decreased; it was depreciated by the scattering of the fluorescent light by the supporting medium. Screens emitting a blue light gave less sharp indications than those which appeared green or yellow, probably owing to the greater scatter of the blue fluorescence. The best screen was not so effective as a photographic film, but it sufficed for the examination of light-alloy castings up to 40mm. thick.

Possibilities and Limitations of Long-Range Exposures [*Grossbildaufnahme*] **with X-Rays.** R. Berthold. (Archiv für das

Eisenhüttenwesen, 1935, vol. 8, Mar., pp. 425–426). Experiments were carried out on a V-weld, a fillet weld and steel pieces of various thicknesses to determine the relative abilities of radiographs taken at short range (*Nahaufnahme*) and at long range (*Fernaufnahme* or *Grossbildaufnahme*) to reveal defects. It appeared that, with the usual intensifying screens, the normal distance of 50–70 cm. between the X-ray tube and the object could be increased to 3–4 m. (thus covering a larger area of the object), provided that a considerable diminution in the sensitivity of detection of defects were acceptable. For making long-range exposures on bridge welds such as are usual to-day, apparatus with a tube potential of 200 to a maximum of 250 kv. suffice. The taking of long-range radiographs with high X-ray tube potentials and no intensifying screens leads only to poor results.

A Focusing Chamber for the X-Ray Reflection Method. F. Wever and A. Rose. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 3, pp. 33–37). A description is given of a focusing chamber for use in the reflection method of making X-ray spectrograms, by means of which the period of exposure can be reduced from one or more hours to 5 to 10 min. without loss of definition.

X-Ray Inspection of High Alloy Castings. F. K. Ziegler and D. W. Bowland. (Metal Progress, 1934, vol. 26, Dec., pp. 22–26). The flaws which occur in castings often cannot be detected by visual inspection alone. In such cases X-ray investigation is a valuable method of revealing the internal defects which may be present. The writers of the article describe the procedure adopted for examining castings of the heat- and corrosion-resistant types, and show radiographs depicting inclusions, cavities, blowholes, and other discontinuities.

The Determination of Orientations of Metallic Crystals by Means of Back-Reflection Laue Photographs. A. B. Greninger. (American Institute of Mining and Metallurgical Engineers, 1934, Technical Publication No. 583).

Interference Measurements in the Infra-red Arc Spectrum of Iron. W. F. Meggers. (Journal of Research of the National Bureau of Standards, 1935, vol. 14, Jan., pp. 33–40). The wavelengths of the stronger infra-red radiations characteristic of integrated light from an iron arc at atmospheric pressure were measured relative to neon standards by the Fabry - Perot interferometer method. Values are given for 91 lines ranging from 7,164·469 to 10,216·351Å. Spectral term combinations indicate that most of these lines require relatively high excitation energies, which accounts for their character and properties. Differences between values from integrated arc light at atmospheric pressure and from the vacuum arc are interpreted as pressure- and Stark-effects. It is suggested that the international

system of secondary standards of wavelength can be extended into the infra-red by using integrated light from an iron arc at 1 atm. pressure.

Sulphur Prints and Sulphide Inclusions. L. Northcott. (Metallurgist, 1935, vol. 10, Feb. 22, pp. 7–10). From a study of steel sections and sulphur prints it was observed that the sulphur prints show a number of dark spots, considerably larger yet fewer in number than the inclusions in the steel, and there was no constant relation between them in size. The sample showing local segregation of sulphide inclusions yielded a print in which the segregation was appreciably exaggerated. It was found possible to identify a large number of the sulphide areas on the sulphur prints with inclusions in the steel. Iron sulphide inclusions were most effective in marking the paper. Of other sulphide inclusions those of duplex structure containing iron sulphide, or solutions rich in iron sulphide, were most active, while silicate inclusions, of course, produced no effect. The intensity of the sulphur print thus depends on the composition of the inclusions (manganese sulphide being less effective than iron sulphide) as well as on the conditions (such as the acid content of the paper) under which the print is made.

Grain Size of Steel Discussed at Convention. (Metal Progress, 1934, vol. 26, Nov., pp. 34–39). Grain size is usually controlled by additions of aluminium in the ladle or the mould. A coarse grain confers good machinability—this is established by tests on Bessemer screw stock ; but fine-grained steels are stronger. Steels which are coarse-grained behave well when forged ; they are denser and the structure is less markedly fibrous. Steels may be specified to be coarse- or fine-grained, according to the carbon content, alloy additions, and duty which they are required to perform.

Grain Size Control and Its Effect on the Mechanical Properties of Forgings. J. M. Robertson. (Metal Treatment, 1935, Spring No., pp. 21–29). The importance of inherent austenitic grain-size is stressed, and certain of the operative factors are examined. Attention is then devoted to the determination of the austenite grain-size by micrographic methods, and to the methods of grain-size control. The influence of grain-size upon the behaviour of the metal under heat treatment is touched on, and the effect upon the mechanical properties is described.

Effect of Deoxidation on Grain Size and Grain Growth in Plain Carbon Steel. C. H. Herty, jun., D. L. McBride and S. O. Hough. (Mining and Metallurgical Investigations, 1934, Co-operative Bulletin No. 65). The growth of crystals in the presence of deoxidisers is briefly touched upon, and the systems involving FeO, MnO, SiO_2 and Al_2O_3 are outlined. The authors then describe experiments carried out to determine the effect

of deoxidising agents. Silicon and aluminium in various forms were used as the deoxidisers, together with manganese. It was found that the grain-size of plain carbon steels is profoundly affected by the method of deoxidation used. In the case of silicon-killed steels slow heating rates confer good refinement; aluminium steels are fine-grained regardless of the heating rate. Highly purified iron-carbon alloys show considerable grain-growth; evidently there is no material to inhibit this effect. In order to prevent grain-growth above the Ac_3 point finely dispersed non-metallic matter should be present. Aluminium-killed steels which have been overheated show good recovery on re-normalising; silicon-killed steels show only partial recovery; this is borne out by impact tests and grain size observations. Since coarse-grained steels are more readily machinable than fine-grained, the machinability may be improved by overheating, and the physical properties restored by re-normalising, in the case of aluminium steels.

The Effect of Deoxidation on the Rate of Ferrite Formation in Plain Carbon Steels. C. H. Herty, jun., M. W. Lightner and D. L. McBride. (Mining and Metallurgical Investigations, 1934, Co-operative Bulletin No. 64). The authors show that variations in grain-size have a pronounced effect on the amount of ferrite formed, and that grain-size variation depends on the method of deoxidation employed. A factor k, the specific reactivity, is introduced to describe the rate at which austenite is decomposed into ferrite and pearlite. They deduce an equation relating the percentage of ferrite formed to the specific reactivity, the specific grain surface, the degree of supercooling and the rate of carbon diffusion. A number of medium carbon steels deoxidised with aluminium and with silicon were studied. Specimens were quenched and examined under the microscope, and the grain surface was estimated from a grain-size count. The authors discuss the effect of supercooling on the grain-size and rate of ferrite formation, and the influence of the intracrystalline precipitation of ferrite. The specific reactivities of fine- and coarse-grained steels, and of steels deoxidised in various ways are calculated, and the use of specific reactivity and grain-size in determining hardenability is demonstrated. It is shown that, although for a certain aluminium-killed steel the specific reactivity is highest, in general the variation in specific reactivity in plain carbon steels is less than the normal differences in grain-size.

Questionnaire on Dendrites, the Monocrystalline State, the Grain of Metals, and the Mechanism of its Growth. L. Dlougatch. (Revue de Métallurgie, Mémoires, 1935, vol. 32, Jan., pp. 23–31; Feb., pp. 85–99). Some time ago the Russian periodical *Metallurg* issued a questionnaire to a number of scientists and metallurgists in England, Germany, France, Japan, Sweden and Russia,

asking them to state their views regarding (*a*) dendrites, (*b*) the monocrystalline state, (*c*) the conception "grain" of a metal, and (*d*) the mechanism of the growth of a grain. The replies received were published in the Nos. 7 and 8 of *Metallurg* for 1932, and in the present articles an abridged translation of these responses is given.

The Form of Combination of Carbon in Hardened and Tempered Steels. F. Wever and G. Naeser. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1934, vol. 16, No. 18, pp. 201–206). The authors record the results of their examination of the residues obtained by the electrolytic decomposition of high-carbon steels, suitably heat-treated, in an attempt to determine the form of combination in which the carbon existed. Before the electrolysis, the specimens were heated and then either quenched in ice-water and tempered or else quenched in metal or salt baths at various temperatures. The residues obtained from tempered steels by electrolysis in ferric chloride solution could be divided into two portions by "sliming" in a magnetic field; one fraction consisted of highly dispersed carbon to which water adhered, and the other was a grey-black powder which was pyrophoric. The carbon contents of the unseparated residues fell with increasing tempering temperatures, from very high values for the untempered specimens to the equivalent of iron carbide (Fe_3C) for tempering temperatures of 700°. The carbon contents of the residues freed from free carbon by sliming grouped themselves about the composition FeC for tempering temperatures of about 300°, and Fe_2C between 300° and 600° C.; the composition of cementite was not reached at tempering temperatures below about 700°. The transition temperatures fell with increasing tempering periods and with decreasing carbon contents in the original steels.

The residues from the steels transformed directly from the austenitic state always contained less carbon than those from the tempered steels. On analysis they proved to be uniform and could not be subdivided by sliming. For transformation temperatures of 400° to 500° their carbon contents were grouped about the composition Fe_2C. Above a certain temperature, which decreased with decreasing carbon content and lay at 400°–500° for 0·6 per cent. of carbon, the composition suddenly jumped to that of cementite (Fe_3C).

In X-ray examinations of the slimed residues the interference lines of cementite only were observed, and no trace of the other carbides could be found. This proves that even at tempering temperatures below 200° cementite is formed in observable amounts; this was confirmed by the magnetic analyses. The conclusions to be drawn from the composition of the residues regarding the carbide phases existing in the steels are uncertain.

With this reservation, the occurrence of high-carbon carbides FeC and Fe_2C may be regarded as probable.

The Primary Structure and Its Influence on the Properties of Steel. F. Rapatz and H. Pollack. (Stahl und Eisen, 1934, vol. 54, Nov. 22, pp. 1201–1209). The primary structure of steel has an effect on the properties in that it may influence the secondary structure: A coarse primary structure engenders a coarse secondary structure in slowly cooled ingots; on more rapid cooling, however, such as in normalising, the secondary is not related to the primary structure. In ledeburitic steels and chill castings, the primary grain is built up of a number of grains of ledeburite. The primary structure is still recognisable after even the most drastic deformation—for instance, in sheets. Coarse primary crystallites, columnar crystallisation and shrinkage cracks at the grain-boundaries are those features of the primary structure which affect the steel adversely, giving rise to excessively fibrous structure, snowflakes and forging cracks. Shrinkage cracks occur more readily in coarse than in fine crystals, and are favoured by rapid cooling of the solidified ingot. Marked columnar crystallisation accumulates the fibrous structure in the core of the forged or rolled piece, and is therefore mostly damaging. Small ingots with comparatively marked crystallisation, therefore, do not always exhibit the best properties. Regarding the formation of snowflakes, the authors regard Bardenheuer's theory as the most likely; according to this theory, segregation plays a part, and for this reason the primary structure must affect the production of flakes. By prolonged heating before forging or rolling and slowly cooling afterwards, it is, however, possible, even in steels liable to flake-formation, to prevent the occurrence of defects. By interrupting the cooling before reaching the martensite point and reheating to about 600°, it is theoretically possible to avoid the transformation of the segregated parts into martensite. Besides the shrinkage cracks, it is the coarse primary crystals, and particularly the coarse elongated crystals of the columnar structure, which decrease the forgeability; prolonged heating before forging can be of assistance in this respect.

The Structure and Formation of Lamellar Pearlite. N. T. Belaiew. (Revue de Métallurgie, Mémoires, 1935, vol. 32, Apr., pp. 145–155). The lamellar structure of pearlite is not a consequence of the fact that this material is a eutectoid. The iron-carbon diagram shows that there is a heavy preponderance (86·5 per cent.) of ferrite over cementite in pearlite, and, further, that a variation of a few degrees of temperature has a much more marked effect on the supersaturation with respect to ferrite than to cementite, so that ferrite tends to impress its own characteristics on the crystallisation of pearlite. The author next discusses the internal structure of a pearlite grain and the distance between

the lamellæ; he then shows that the ferrite in pearlite is built up of minute cubes, the dimensions of which are constant, and points out the effect of this on the interlamellar distance in the pearlite; he touches on the apparent and real thickness of the cementite lamellæ, which is too small to be resolved by the most powerful microscope, and he also deals with the relation between the γ grain and the α grain in a eutectoid, and the number of crystal orientations in the grains of pearlite produced from a given γ area. Finally, on the basis of the foregoing considerations he discusses the formation of pearlite. Isolated lamellæ are never found—only grains of pearlite; this requires that the γ–α transformation must occur instantaneously throughout the whole mass which will form the α grain. A rapid increase in the supersaturation with respect to carbon causes the precipitation of carbide throughout the grain. The first films of cementite therefore lodge themselves parallel to certain α crystallographic planes in process of formation. The direction of these planes is also parallel to that of the formation of the grain. The crystallisation of these lamellæ therefore takes place along the same course and at the same time as the γ–α transformation of the iron. The distance between parallel crystallographic planes is determined by the speed of diffusion of the carbon across the α lattice and by the arrangement of the ferrite in course of formation in units about 250$\mu\mu$ in size. Assuming the distance between neighbouring lamellæ to be about 300$\mu\mu$, a carbon atom need travel no more than 150$\mu\mu$ to reach one of them, but owing to the short time taken for the "instantaneous" crystallisation (say, $\frac{1}{20}$ sec.) it has to travel with a velocity of about 3 cm. per sec. —a considerable speed for a phenomenon such as diffusion at about 700° in a solid medium already fairly rigid.

The Thermal Decomposition of Iron Carbide Fe_3C. G. Naeser. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1934, vol. 16, No. 19, pp. 211–212). It is shown that the temperature at which the decomposition of pure cementite begins lies between 1,050° and 1,060° C.

Nodular Troostite. F. F. Lucas. (Metal Progress, 1935, vol. 27, Feb., pp. 24–28). The formation of troostite on quenching is dealt with, and the structure of hot-rolled high-carbon steel rod is examined. It was found that coarse well-laminated pearlite is fully resolved at high magnifications. Certain areas which appeared white or cloudy, showed clear stratification under high power. Hence the pearlite forms from the troostite.

Influence of Silicon on the Stability of Cubic Martensite. H. Bumm and U. Dehlinger. (Stahl und Eisen, 1935, vol. 55, Apr. 25, p. 467). On quenching specimens of steels containing no silicon, they were found to give no X-ray diffraction lines corresponding to the tetragonal lattice of martensite, but only more or less

broad lines of a cubic body-centred lattice, such as that of ferrite ; on adding 0·3 per cent. of silicon the tetragonal lattice reappeared. By specially rapid quenching (using a paste which prevented the formation of a layer of steam on the surface of the specimen) it was possible to cause the formation of a tetragonal lattice in the silicon-free metal. On annealing at above 90° the tetragonal X-ray spectrogram transformed first into a broadened and later into a clearly cubic type. The microstructure remained martensitic. These tests prove the existence of "cubic martensite," that is, a condition with a martensitic structure and higher hardness, but a cubic body-centred lattice. It is thought that the silicon acts directly by slowing up the formation of the cubic lattice from the tetragonal martensite.

X-Ray Investigation of Austenite and Martensite in some Special Steels. Z. Nishiyama. (Kinzoku No Kenkyu, 1934, vol. 11, Nov., pp. 529–538). The crystal structure of the austenite and martensite in alloy steels (containing chromium, nickel or manganese) was determined by X-rays. The austenite is found to possess a face-centred cubic lattice, and the martensite has a body-centred tetragonal lattice. The martensite in high-manganese steel which has been quenched and tempered consists mainly of the hexagonal phase such as is present in the binary iron-manganese alloy.

Dependence of Rate of Transformation of Austenite on Temperature. J. B. Austin. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 590). The curve representing the variation of the rate of decomposition of austenite with temperature can be represented with fair accuracy by the equation

$$t = \frac{Ke^{0.03\Delta T}}{\Delta T^3}$$

where t is the time required for the reaction to start, K is an arbitrary constant, and $\triangle T$ is the temperature interval below the equilibrium.

Reactions in the Solid State I.—Initial Course of Subcritical Isothermal Diffusion Reactions in Austenite in an Alloy Steel. H. A. Smith. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 602). The author describes an investigation carried out on the decomposition of austenite in an alloy steel (manganese 6·48, carbon 0·92 per cent.) at a temperature of 450° C. Microscopic observation was employed in addition to measurements of dilatation, electrical conductivity, hardness and other physical properties.

Study of the Transformations of the Austenite in a Chromium Steel. S. Steinberg and V. Susin. (Revue de Métallurgie, Mémoires, 1934, vol. 31, Dec., pp. 554–559). The authors have

made a magnetometric and microscopic study of the transformations of the austenite in a chromium steel (chromium 12, carbon 2 per cent., approx.). To examine the influence of the heating temperature on the Ar″ point (initial temperature of transformation of austenite into martensite) the small specimens were heated to various temperatures, cooled to 500° C. in a lead bath, and placed in a magnetometer tube at the same temperature; as they cooled down the intensity of magnetisation was measured periodically. To examine the transformation of austenite at a constant temperature, the specimens were heated at 1,050° for 3 min., cooled in a lead bath at 500°, and then placed in the magnetometer or in a thermostat; they were held for various periods at a constant temperature (between 650° and 150° in 50° steps), and the magnetisation was measured at intervals. The results are recorded diagrammatically. The authors discuss the influence of the partial transformation of austenite in three different temperature ranges on the initial temperature of martensite formation (Ar″ point), and conclude by touching on the transformation of austenite during the tempering of steel quenched or cooled below Ar″.

X-Ray Investigation of the Mechanism of the Transformation from Face-Centred Cubic Lattice to Body-Centred Cubic. Z. Nishiyama. (Science Reports of the Tôhoku Imperial University, 1934, vol. 23, No. 4, pp. 637–664). An investigation was conducted with the object of determining the mechanism of the change from the face to body-centred lattice, using a single crystal of iron-nickel alloy containing 30 per cent. of nickel. X-ray photographs were taken and the results compared with those to be predicted by theory. The author considers that the experimental facts cannot be explained by the theories hitherto put forward, and suggests an alternative mechanism.

The Electron-Optical Observation of Transformations in Iron at Temperatures between 500° and 1,000° C. E. Brüche and W. Knecht. (Zeitschrift für technische Physik, 1934, vol. 15, pp. 461–463). The authors give an account of first experiments in tracing the structural transformations in iron at annealing temperatures by means of the electron microscope.

The A_1 Transformation Range in Abnormal Steels. H. Cornelius. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Apr., pp. 461–462). The temperatures of the Ac_1 and Ar_1 changes of a large number of normal crucible steels and abnormal pure carbonyl steels, with carbon ranging from 0·1 to 1·7 per cent., were determined. The results confirm basically the suggestion of Duftschmid and Houdremont (Stahl und Eisen, 1931, vol. 51, p. 1613) that the development of an abnormal structure is a property of pure iron also. In this the rate of diffusion of carbon is very great, which is apparent from the early commencement of

the Ac_1 and Ar_1 transformations and the small hysteresis between them. In abnormal steels the cementite migrates in the α- and in the γ-iron towards the first cementite particles to precipitate, and so causes the balling up of the cementite and the occurrence of ferrite even in hypereutectoid steels.

An Equilibrium Diagram for Four-Component Alloys. V. Fischer. (Zeitschrift für Metallkunde, 1935, vol. 27, Apr., pp. 88–89). The author presents an orthogonal plane system of co-ordinates for the equilibrium diagram of mixtures of any four components, and applies it to the case of manganese-copper-iron-nickel alloys.

The Existence of a Transformation of Exactly Second Order. U. Dehlinger. (Zeitschrift für physikalische Chemie, 1935, vol. 28, Section B, pp. 112–118). According to an earlier calculation of the author, a continuous transition from a normal transformation of the first order through a critical point to a transformation of exactly second order can be brought about during the transformation from the "ordered" to the "disordered" atomic arrangement in metallic solid solutions by varying a parameter (dependent, among other things, on the pressure) representing the coupling between lattice change and atomic distribution. Only in the limiting case does the transformation become of the third order. It appears that Fe_3Al is realised experimentally as a transformation of the second type.

Steels for the User IV.—The Effect of Carbon in Steel. R. T. Rolfe. (Iron and Steel Industry, 1934, vol. 8, Dec., pp. 85–88). The author discusses the allotropic forms of iron and the iron-carbon equilibrium diagram. The mechanism of cooling is dealt with, and attention is devoted to the microstructures of steels, and the relation between strength, carbon content and ductility.

Transformation, Hardening and Tempering Phenomena in Steels containing up to 1 per cent. of Carbon and up to 12 per cent. of Chromium. W. Tofaute, A. Sponheuer and H. Bennek. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, May, pp. 499–506). On the basis of experiments made on specimens containing five different carbon contents and five different chromium contents, the authors have drawn up sections through the three-dimensional iron-chromium-carbon equilibrium diagram, five parallel to the iron-chromium side and five parallel to the iron-carbon side. With increasing chromium contents the transformations are displaced, either upwards or downwards, in such a way as to delimit the γ range, and simultaneously the ability of the γ-iron to dissolve carbon decreases. The rate of cooling necessary to produce hardening is considerably decreased by additions of chromium. With the occurrence of the special carbide $(Cr,Fe)_7C_3$, in order to obtain maximum hardness in the hypereutectoid steels, the hardening must be effected from temperatures just below the solubility surface

for the carbide. The depth of hardening is improved by raising the chromium contents; nevertheless, the complete hardening throughout a 60-mm. section without the occurrence of overheating effects could only be obtained in the presence of the special carbide $(Cr, Fe)_7C_3$ which only dissolves at very high temperatures. Steels containing this special carbide are particularly able to retain their hardness on tempering; this, as is the case with other steels containing special carbides, is due to a precipitation of carbide. As the quenching temperature is raised (that is, with increasing quantities of the carbide dissolved), so the retention of hardness increases. With chromium contents of 5 per cent. and more, large amounts of residual austenite remain after quenching from very high temperatures; on tempering at 500° C. these break down, and increase still further the retention of hardness during the first time of tempering. Even in steels which contained no special carbide, a slight retarding effect of chromium on the martensite breakdown was observed.

Changes of Properties of Irreversible Ternary Iron Alloys due to Heat Treatment. W. Köster. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, May, pp. 491–498). On tempering quenched specimens of iron-cobalt-manganese, iron-cobalt-chromium, and iron-manganese-chromium steels, it was found that in alloys with slight hysteresis and a narrow α–γ transformation range, tempering effects produced by heating below the commencement of the transformation were made simply reversible through the transformation. In alloys with marked hysteresis and an extended α–γ transformation range, heating in this temperature range produced remarkable changes of properties, which were caused by the fact that the proportion of γ solid solution formed at the higher temperature was retained down to room temperature and was very stable. The magnetic saturation decreased and the specific gravity increased. The great increase in the coercive force accompanying this change of structure was noteworthy. The alloys containing cobalt showed a tempering phenomenon which was intensified as the cobalt content was raised and was more marked in specimens with high hysteresis than in those with low hysteresis. The direction of the change of properties—decrease of the coercive force, electrical resistance and specific gravity, and increase of the magnetic saturation and remanence—pointed to the setting-up of a regular atomic distribution as the cause. The transition from the disordered to the ordered atomic arrangement was accompanied by a sometimes very considerable increase of hardness. In the quenched condition (disordered atomic arrangement) the electric resistance of the ternary alloys rose with the cobalt content, as would be expected in a series of solid solutions. In the tempered condition (ordered atomic arrangement) the resistance values were very low (as is known

for the pure iron-cobalt alloys). Heat treatment in the α-γ transformation range led to an increase or a decrease of the resistance according to the composition of the alloy; this depended on whether the resistance of the γ phase was greater or less than that of the disordered or ordered α solid solutions. The resistance of the γ solid solutions of the iron-manganese alloys was lower than that of the α solid solutions.

Transformations in Iron-Aluminium Alloys. C. Sykes and H. Evans. (Iron and Steel Institute, May, 1935; this Journal, p. 225).

Alloys of Iron and Chromium. V. N. Krivobok. (Transactions of the American Society for Metals, 1935, vol. 23, Mar., pp. 1–60). The author reviews the work of previous investigators on the iron-chromium diagram and describes his own investigations on the constitution and properties of iron-chromium alloys. The cause of brittleness in the 18 per cent. chromium-iron alloys, and the important influence of nitrogen on iron-chromium alloys of very low carbon content were studied.

Linear Thermal Expansion and Transformation Phenomena of Some Low-Carbon Iron-Chromium Alloys. J. B. Austin and R. H. H. Pierce, jun. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 589). The linear thermal expansion of five iron-chromium alloys of low carbon content (0·03 per cent. or less) containing between 3 and 11 per cent. of chromium was measured. Values are given for the mean and true expansion coefficients between room temperature and 800° C. The behaviour of these alloys in passing through the alpha-gamma inversion (A_3 point) at a constant rate of heating or cooling was studied dilatometrically. The transformation temperatures on cooling are very much lower than those observed on heating, an effect that is shown to be related to the rate of transformation of austenite to ferrite. It is shown that this lag can be estimated from the curve giving this rate of transformation as a function of the temperature. The data illustrate strikingly that in many cases the use of cooling curves, or of any measurement in which the specimen is cooled, may, and frequently does, lead to large errors. The lag on heating through the inversion is very much smaller. The dilatometer readings show that the rate of transformation of the alloys on cooling is of the same type as the rate for nickel and manganese steels previously discussed by Bain. The limits of the two-phase region of the gamma loop have been tentatively assigned. The shape of the gamma loop is, in accord with expectation, consistent with the change in distribution of chromium between the alpha and gamma phases with change of temperature and of total chromium content.

X-Ray Investigations on the System Iron-Chromium-Nitrogen.

S. Eriksson. (Jernkontorets Annaler, 1934, vol. 118, pp. 530–542). The author has studied the Fe–Cr and Cr–N systems, and has made X-ray investigations of the iron-chromium nitrides formed by passing ammonia over heated Fe–Cr alloys. The presence of an intermediate phase in the iron-chromium system, corresponding to the formula FeCr, has been confirmed. The β-phase in the Cr–N system has been found to possess a "super-structure," the *a* axis of the cell being $\sqrt{3}$ times that of the *a* axis in the ordinary hexagonal lattice. Equilibrium diagrams of the Fe–Cr–N system are included.

The Iron-Cobalt-Titanium System. W. Köster and W. Geller. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Apr., pp. 471–472). On the basis of observations of the structure and of the behaviour of the alloys when submitted to a precipitation-hardening heat treatment, the diagram of the iron-cobalt-titanium system up to 22 per cent. of titanium has been drawn up. The compound Fe_3Ti appears to form an uninterrupted series of solid solutions with a compound Co_3Ti, the existence of which seems to be very probable. From the melt, α and γ solid solutions can also separate out. The eutectic equilibrium of the iron-titanium system :

$$\text{Melt} = \alpha + Fe_3Ti,$$

as well as the peritectic equilibrium of the iron-cobalt system :

$$\text{Melt} + \alpha = \gamma$$

take place at lower temperatures on the addition of the third element (cobalt or titanium), and end at about 1,150° C. in a four-phase plane with the equilibrium :

$$\left.\begin{matrix}\text{Melt} + \\ \alpha \text{ solid solution}\end{matrix}\right\} = \begin{cases}(Fe_3Ti,\ Co_3Ti) \text{ solid solution} \\ + \ \gamma \text{ solid solution}\end{cases}$$

From here stretches down to lower temperatures the three-phase equilibrium :

$$\text{Melt} = \gamma \text{ solid solution} + (Fe_3Ti,\ Co_3Ti) \text{ solid solution},$$

which passes into the eutectic equilibrium of the cobalt-titanium system, and the three-phase equilibrium :

$$\alpha \text{ solid solution} = \begin{cases}\gamma \text{ solid solution} + \\ (Fe_3Ti,\ Co_3Ti) \text{ solid solution}\end{cases}$$

which reaches down to room temperature.

The Carbides in Steels with Low Vanadium Contents. W. Bischof. (Archiv für das Eisenhüttenwesen, 1934, vol. 8, Dec., pp. 255–258). By resistance measurements on annealed and quenched low-vanadium steels and by chemical and electrolytic separation of the carbides, it was determined that in low-carbon vanadium steels the vanadium carbide V_4C_3 occurs along with iron carbide, and that in steels with higher carbon contents the carbide VC and cementite are present.

The Occurrence of High Crystallisation Force in the Formation of Iron-Zinc Alloys. E. Scheil. (Zeitschrift für Metallkunde, 1935, vol. 27, Apr., pp. 76–77). If a prismatic specimen of steel is dipped in molten zinc at about 450° C. for some time a remarkable growth of "hard zinc" forms; growth occurs at right-angles to the faces of the steel and gives rise to bodies of curious shape. If the steel specimen is cylindrical in shape the edge of the hard zinc layer cracks. Crystals of $FeZn_7$ are formed, but none of the composition $FeZn_3$. The force of crystallisation in these layers is very great, amounting to over 6 kg. per sq. mm. at 450°, and thus exceeds very considerably previously measured values of the force of crystallisation.

On the Specific Heat of Iron-Carbon System at High Temperatures, and the Heat Changes accompanying those of Phase. S. Umino. (Science Reports of the Tôhoku Imperial University, 1935, vol. 23, Mar., pp. 665–793). The specific heats were obtained by the method of mixtures, using a water calorimeter. Specimens with carbon contents of from 0·07 to 5·07 per cent. were used, the temperatures varying from 900° C. upwards. The heat contents were deduced and the iron-carbon equilibrium diagram was redetermined on this basis. Heats of reaction (peritectic and eutectic) were derived, together with heats of fusion, solution, and mixture.

On the True Specific Heat of Some Metals and Alloys. K. Honda and M. Tokunaga. (Science Reports of the Tôhoku Imperial University, 1935, vol. 23, Mar., pp. 816–834). Essentially, the apparatus employed consisted of a highly evacuated Dewar vessel containing the specimen, upon which the heating coil was wound; into the specimen a thermocouple was inserted. The Dewar vessel was immersed in an oil bath at constant temperature. The specific heats were evaluated by equating the heats supplied and absorbed, suitable corrections being applied. The results obtained on certain non-ferrous alloys agreed well with those of other investigators.

The Specific Heat of Iron Carbide Fe_3C. G. Naeser. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1934, vol. 16, No. 19, pp. 207–210). The heat content of pure crystalline iron carbide, Fe_3C, was measured between $-190°$ and $+770°$ C., and the average and true specific heats were calculated. The Kopp-Neumann law of the additivity of the atomic heat does not apply to cementite. The heat evolution of the magnetic transformation amounts to about 1·5 cal. per grm. The value for the heat of formation of cementite measured at room temperature, as given in the literature, was calculated to higher temperatures.

Contribution on the Present Position of the Vapour-Pressure/Temperature Relationship of Metals. W. Leitgebel. (Metall-

wirtschaft, 1935, vol. 14, Apr. 5, pp. 267–270). In a diagram showing the vapour-pressure/temperature relationship for a number of metals, the curves for iron and for a number of other elements of interest to the ferrous metallurgist, are included.

HEAT-RESISTANT AND ACID-RESISTANT ALLOYS.

What Demands can be made of Corrosion- and Heat-Resisting Irons and Steels Nowadays? A. Lissner. (Montanistische Rundschau, 1935, vol. 27, Mar. 16, pp. 1–7). The author reviews the properties of modern corrosion- and heat-resisting irons and steels of various types.

Rôle of the Alloying Elements in the Rustless Steels. E. Prétet. (Chimie et Industrie, 1935, vol. 33, May, pp. 1061–1063). The author describes briefly the effects of special elements in rustless steels: They may modify the properties of the basis solid solution in which they themselves dissolve; they may determine the nature and number of phases capable of existing in the alloy and permitting various heat treatments; finally, they may control the nature of the non-metallic phases separating before and during the solidification of the metal, which may have an influence on the quality of the material.

Stainless Steels. H. Bull. (Iron and Steel Industry, 1935, vol. 8, Mar., pp. 242–245). Stainless steels used for the manufacture of cutlery and hollow-ware, of both plain chromium and nickel-chromium types are considered, and the heat-treatment procedure is described.

The Properties, Characteristics and Uses of Stainless Steels. S. A. Main. (Journal of the Royal Society of Arts, 1935, vol. 83, pp. 673–700: Iron and Coal Trades Review, 1935, vol. 130, Mar. 22, pp. 491–492). The author discusses at length the mechanical treatment, characteristics, weld decay and corrosion resistance of the stainless steels.

Stainless Steels in Aircraft Construction. W. H. Hatfield. (Royal Aeronautical Society, 1934, Dec. 13: Iron and Coal Trades Review, 1934, vol. 129, Dec. 28, pp. 1018–1019). A review of progress in the application of stainless steels since 1917. In addition to the original 14 per cent. chromium alloy, steels containing 18 per cent. of chromium and 2 per cent. of nickel, and 18 per cent. of chromium and 8 per cent. of nickel have been developed. The former are hardenable by heat treatment, whilst the latter are austenitic but amenable to cold-working. Both types are highly corrosion-resistant. These steels carry low carbon contents, hence care must be taken during welding not to increase the carbon in the weld-metal. Stainless steels require special care in welding if the properties of the material

are not to be impaired. Tests have shown that non-corrodible steels are not liable to contact corrosion, but the alloys may fail as a result of induced stresses when subjected to forming or machining operations; the stressed areas are likely to become corroded. Steels are now available which combine high strength and adequate ductility with freedom from corrosion. Stainless steels have been successfully used for floats, flying-boat hulls and land machines.

Stainless Steel in Aircraft Construction. F. Flader. (Transactions of the American Society of Mechanical Engineers, 1934, vol. 56, pp. 295–300). The characteristics of stainless steel are considered; in particular, the strength-to-weight ratio, tensile strength, strength of columns, deflection of beams, are all compared with the values obtainable from aluminium alloys. Some attention is paid to the methods of fabricating stainless steel members; spot welding appears to be much the most suitable method.

Pitting of 18-8 in Navy Use. (Metal Progress, 1935, vol. 27, Feb., pp. 37–39). Several failures occurred in the corrosion resistance of 18/8 stainless steel used in the U.S. Navy. Pitting was observed; several explanations have been advanced, and the U.S. Navy is carrying out experiments in an endeavour to trace the cause of the trouble.

On the Study of Non-Corrosive Steels for Soya Bean Souse. H. Sekiguchi. (Kinzoku No Kenkyu, 1935, vol. 12, Jan., pp. 67–78). A series of corrosion tests was carried out with the purpose of evaluating the resistance to attack by soya bean souse. Steels containing 7 per cent. of chromium, or more, were found to behave best. Nickel steels were less effective.

Highly Heat-Resistant Chromium-Aluminium-Iron Alloys. A. Grunert, W. Hessenbruch and K. Schichtel. (Elektrowärme, 1935, vol. 5, pp. 3–12). The authors describe in detail the properties of the highly heat-resistant Cr–Al–Fe alloys: Heat resistance, melting points, influence of certain alloying elements, oxide formation, mechanical characteristics, &c. The difference in the behaviour of these alloys from that of the Cr–Ni alloys is due to the fine structure. The Cr–Ni alloys are susceptible to intergranular corrosion, but the Cr–Al–Fe alloys are not. The latter are serviceable at temperatures up to 1,300° C.

Selection of Materials for Cast Valves and Fittings. A. M. Houser and H. L. Moe. (Steel, 1934, vol. 95, Nov. 26, pp. 32–35). The spheres of usefulness of carbon steel, Ni–Cr–Mo steel and nickel steel for valve castings are indicated; the former is used for moderate duty, the Ni–Cr–Mo steel is employed for high temperatures and pressures, and nickel steel is used for sub-zero temperature operation. For welded work, to withstand high temperatures, a carbon steel with 0·50 per cent. molybdenum

is useful. For corrosion resistance a chromium steel containing molybdenum is found to be satisfactory.

5 Per Cent. Cr Still Tubes. E. S. Dixon. (Metal Progress, 1935, vol. 27, Feb., pp. 33–36). Under certain conditions 4–6 per cent. chromium tubes show a corrosion resistance greatly superior to that of carbon steel, when used in petroleum refinery plant. They may be successfully welded if proper electrodes are used; preheating is necessary, and the weld should be annealed after completion. They do not fail suddenly under high-temperature conditions.

CORROSION OF METALS.

(For Coating of Metals, *see* p. 438).

Third Report of the Corrosion Committee. (Iron and Steel Institute, 1935, Special Report No. 8). Section A of this report is introductory in character and deals with the constitution of the Committee and the present position of the Committee's work. Sections B and C describe the progress of the Committee's field tests on atmospheric corrosion and of their work on marine corrosion, respectively; the latter includes a report by J. C. Hudson and R. H. Myers on the progress of the tests on the plates built into the barge "Cactus," a report by R. H. Myers on the corrosion of the pontoons supporting the landing stage at Gosport, and the results of some experiments conducted by H.M. Admiralty on the corrosion of welded plates. Section D is devoted to the work of the old Sub-Committee on Laboratory Corrosion Tests, which has now been renamed the Laboratory Research Sub-Committee. In this Section will be found the following papers containing the results of several researches by independent investigators, bearing on the general problems under consideration by the Committee: A paper by R. B. Mears on metallurgical factors influencing the probability of corrosion of iron and steel; a paper by G. D. Bengough and F. Wormwell dealing with the design, interpretation and uses of standard corrosion tests in salt solutions and industrial waters; two papers by K. G. Lewis and U. R. Evans on the effect of mill scale on the performance of paint, and on the orders of merit of ten ferrous materials exposed to corrosion in different conditions at different stations, respectively; and reports by J. C. Hudson on a second series of atmospheric corrosion tests on wires, on the progress of subsidiary paint tests at Birmingham and Farnborough, and on the results of the tests on the ageing of hard-drawn mild steel wires, conducted by several members of the Committee and other investigators. Finally, information on corrosion and related matters submitted

to or obtained by the Committee has been summarised in Section E. This includes information on the resistance to corrosion of steel sleepers in coal mines, and the results of examinations of an old wrought iron rail and a sample from the old cast-iron bridge at Coalbrookdale. It is the intention of the Committee to present their Reports annually in the future.

The Fight Against Corrosion. (Aciers Spéciaux, 1934, vol. 9, Oct., pp. 285–610). The whole of this issue of this publication is devoted to articles on the corrosion of metals and its prevention. Among the papers are the following :

General.—Theories of Corrosion.

A. PORTEVIN : Corrosion and the use of metals.

GRARD : Atmospheric and marine corrosion of metallurgical products.

G. CHAUDRON : Theories of corrosion.

L. PERSOZ : Corrosion-fatigue.

Corrosion-Resisting Alloys.

A. MICHEL : Rustless steels.

P. CHEVENARD : Corrosion-cracking of the ferro-nickels in steam and the metals used for turbine blading.

H. JOLIVET : Corrosion of metals and alloys at high temperatures.

J. GALIBOURG : Mechanical properties in the hot and cold states of metals subjected to corrosion.

E. HERZOG : Copper steels.

M. BALLAY : The corrosion of ordinary and austenitic cast irons.

The Working of Corrosion-Resisting Alloys.

P. BENLOZ : Heat treatment of rustless steels.

G. VÉRY : Modification of the mechanical characteristics of corrosion-resisting steels by cold-work.

C. AURIBAULT : Pickling-polishing of rustless steel.

A. MICHEL and L. GIRY : Machining of rustless steels.

A. LEROY : Welding of rustless steels.

Corrosion Tests.

R. CAZAUD : Corrosion tests on metallurgical products.

R. LEGENDRE : Sea-water : its definition for corrosion tests.

SOCIÉTÉ DES TRÉFILERIES ET LAMINOIRS DU HAVRE : Accelerated tests on corrosion by sea-water.

Protective Coatings.

J. COURNOT : Protective coatings.

P. ORLOWSKI : The preparation of metallic surfaces by pickling and de-greasing before applying superficial coatings.

C. BOULANGER : Chemical coatings.

J. BARY : Protection by chemical means.

G. MONTELUCCI : Hot-coating of steel with cadmium-zinc eutectic.

R. LECŒUVRE : Protection against corrosion by the utilisation of secondary electrolytic actions.

MISS S. FRANÇOIS : Metallisation.

J. LAISSUS : Protection of metallurgical products against corrosion by metallic cementation.

J. LOISEAU : Chromium-plating and cadmium-plating.

Industrial Documentation.

Industrial applications of chromium-nickel steels.

Manufacture and researches in metallurgy of special steels. The Aciéries d'Imphy and the fight against corrosion.

The final deoxidation of steels.

Sandvik rustless steels.

M. DUQUENOY : Considerations on the semi-rustless steels.

The Maubeuge Steelworks.

Esco open-hearth copper steel of the Société d'Escaut et Meuse.

Hauts-Fourneaux de la Chiers : Division des Forges de Vireux-Molhain (Ardennes). [Brief details of corrosion-resisting products.]

Forging steel for structural hardening of the Forges de la Providence.

Etablissements Schneider. I.—Ferro-silicon castings. II.—High-chromium cast irons.

High-quality cast irons with the addition of chromium-nickel in small grains.

M. DAMIEN : The cleaning of metals by trichlorethylene.

Cifer. New method for the chemical protection of metals against oxidation. [An oily substance which is applied to metals and baked on.]

P. ORLOWSKI : Udylite. [A method of protection by coating with cadmium.]

Metallisation by pulverisation of metal, or the Schoop process.

Solution of some problems of corrosion protection.

An anti-rust enamel. Tuck-amel No. 3.

Fatigue testing machine for the determination of the endurance of test-pieces of elements of construction.

Corrosion. T. M. Service. (Journal of the West of Scotland Iron and Steel Institute, 1935, vol. 42, Jan., pp. 53–60). In general, there are two theories of corrosion : The electro-chemical theory, and the colloidal theory. The former appears better able to account for the phenomena observed. It is considered that differential aeration, leading to differences in oxygen concentra-

tion, is largely responsible for corrosion. This is borne out by experiments, and by the behaviour of condenser tubes, ships' plates, &c., in which areas not readily accessible to oxygen are found to act as centres of corrosion. Pitting and localised corrosion may be explained on this basis. If the corrosion product is insoluble, attack will diminish or cease ; if it is soluble, corrosion will proceed apace.

Corrosion Problems. J. Johnston. (Industrial and Engineering Chemistry, 1934, vol. 26, Dec., pp. 1238–1244). The author restates the chief factors causing corrosion, and suggests that the rate of diffusion of the reacting materials through the surface film is of importance. He discusses the conditions which give rise to corrosion, and the methods adopted to delay or inhibit attack. In general, susceptibility is found to depend as much on the character of the media surrounding the metal as on the metal itself.

Generalities on the Corrosion of Iron and Steel. J. Sentenac. (Arts et Métiers, 1935, vol. 88, Apr., pp. 81–83). The author first discusses Evans' theory of corrosion, and then deals more particularly with the corrosion of buried metal (pipes, &c.), set up by (*a*) stray electric currents, (*b*) electrolytic action of the soil itself, and (*c*) direct chemical attack by certain acid soils.

Considerations on the Possibilities of the Corrosion-Protection of Metals. M. Straumanis. (Korrosion und Metallschutz, 1935, vol. 11, March, pp. 49–53). The author points out that corrosion-protection largely resolves itself into the problem of controlling the rate of corrosion ; he gives a formula relating the various factors which influence the corrosion rate and discusses its implications.

Voltaic Couples and Corrosion. O. P. Watts. (The Electrochemical Society, 1935, Preprint 67–1). The author throws doubt upon the view that voltaic action is essential to corrosion, and further suggests that the presence of small impurities cannot account for corrosion. He classifies the types of corrosion as (*a*) corrosion without displacement, (*b*) corrosion by displacement of a metal, (*c*) corrosion by displacement of hydrogen. Experiments with voltaic couples in de-aerated solutions were carried out, using sodium chloride solutions, sulphuric acid, and sea-water ; tests with double-salt solutions were also performed. Special care was taken to eliminate air from the apparatus used in the experiments. The results of a large number of such tests are given in tabular form ; they lead to the conclusion that the removal of air prevents corrosion.

The Theory of Corrosion. III.—The Pore Theory of Corrosion and of the Protection of Metals against Corrosion in Aqueous Solutions. W. J. Müller. (Korrosion und Metallschutz, 1935, vol. 11, Feb., pp. 25–34). Starting out from the theory of local

elements and Evans' theory, that oxide layers are the cathodes of the local elements, the author has developed a theory of the corrosion of metals in solutions based on determinations of the passivity of metals. On this basis he shows that the extent of corrosion is dependent in the first place on the size of the pores in the natural layer of coating. If the pore size remains below a certain value in the solution, then the metal becomes passive, indicated by the potential becoming more "noble" according to the time law of self-passivification. If solution of the coating occurs, and, therefore, an enlargement of the pore size, then the metal becomes corroded, as can be clearly shown by reference to the magnitude of the local-element current and potential. In the protective action of metallic coatings, the stability of the oxide layer is determinative; the experimental application of this point of view in regard to paints is discussed. Intercrystalline corrosion is dependent principally on the fact that the structure of the metal is interrupted at the grain boundaries, in consequence of which the pores exist principally at these boundaries; an example of this is provided by the anodic behaviour of austenitic and martensitic *V2A* steels. The author has endeavoured to show that the fact—revealed by the coating theory of the phenomena of passivity—that coating layers are never free from pores, leads, when carried to a logical conclusion, to a relatively simple theory which provides an explanation of the connection between the corrosion and the e.m.f. of a metal in a solution, and also of the phenomenon of intercrystalline corrosion.

Improved Method for Determining the Corrosion Resistance of Cr and Cr-Ni Steels. C. M. Johnson. (Iron Age, 1935, vol. 135, Feb. 7, pp. 12–15, 84). Particulars are given of the apparatus and methods used by Huey for testing the corrosion-resistance of chromium and chromium-nickel steel, by prolonged boiling in concentrated nitric acid of 65 per cent. acidity by weight. Huey's apparatus has several drawbacks and the present author has introduced certain improvements which are described.

Influence of the Method of Immersion of Samples in Corrosion Tests. J. Cournot and M. Chaussain. (Comptes Rendus, 1934, vol. 199, pp. 1410–1411). The authors have investigated the speed of corrosion of aluminium, duralumin, iron and soft steel in sea water by (*a*) alternate immersion and removal of the sample; (*b*) immersion of the sample, but permitting evaporation to proceed until part of the sample is uncovered; (*c*) shallow immersion but replacing the water as it evaporates and (*d*) deep immersion (50 cm.).

A New Method of Measuring Corrosion of Metals. W. R. van Wyk. (Industrial and Engineering Chemistry, Analytical Edition, 1935, vol. 7, Jan. 15, pp. 48–53). The author describes a method whereby even the slightest corrosion can be measured

quantitatively with great accuracy. Extremely thin layers of metal (about 8×10^{-6} cm. thick) are sublimed on glass plaques in high vacuum and subjected to corrosive action. The extent of corrosion is measured by determining the coefficient of the light-transmissibility of the metal-coated plaques. With an optical apparatus of great precision it is possible to measure a change in thickness of even one atomic diameter. The procedure is described.

Methods of Determining the Thickness of Steel Plates and Castings. G. M. Shaw. (The Institution of Civil Engineers, 1934, Selected Engineering Papers, No. 168). In order to determine the extent to which corrosion has proceeded in the case of steel plates, castings and so forth, it may be useful, and perhaps necessary, to ascertain the thickness of the material. Examinations made *in situ* require a new technique, since plates often cannot be separately investigated, whilst drilling is not always desirable. Apparatus which depends on variations in magnetic flux has been used for the measurement of plate thickness, but the method described by the author employs X-rays. The rays are made to throw images of tungsten wire on to a photographic film, placed behind the plate under examination. This enables the thickness of the plate to be estimated. The results obtained are in concordance with those derived from direct measurement.

Apparatus for Producing Uniform Scratches on Metal Surfaces. R. B. Mears and E. D. Ward. (Journal of the Society of Chemical Industry, 1935, vol. 53, Dec. 14, pp. 382T–384T). Illustrated particulars are given of a machine designed for making reproducible scratches on a series of test specimens, such as are used in corrosion research and in investigations of painted and coated metals.

Some Problems of Intercrystalline Corrosion in the Domain of Steels. E. Houdremont and P. Schafmeister. (Aciers Spéciaux, 1934, vol. 9, Sept., pp. 258–268). The authors present a general discussion (based on their own work and that of other investigators) of intercrystalline corrosion (*a*) in rustless steels (with high contents of nickel or nickel and chromium), and (*b*) in mild steels (such as boiler plates). Brief mention is made of two corrosion tests in which the specimens are under stress during test; in the first, elastic tension is applied, while in the other, the specimen is first bent plastically to a stirrup shape and is then bent further elastically, the specimen being held thus during the corrosion test.

The Intercrystalline Corrosion Phenomenon as Observed in Certain Chromium-Nickel Corrosion-Resisting Steels. W. H. Hatfield. (Metal Treatment, 1935, Spring No., pp. 30–32). This article contains a brief description of the intercrystalline corrosion phenomenon which is known to take place with certain

austenitic stainless steels. The connection between crystalline disintegration and carbide precipitation is commented on.

Thermomagnetic Study of the Heterogeneity of Solid Solutions. P. Chevenard. (Fourteenth Congress on Industrial Chemistry, 1934 : Génie Civil, 1934, vol. 105, Dec. 15, pp. 558–560). Some ferro-nickels (containing a little chromium) undergo " fissuring corrosion " when placed in steam or in hot moist gases ; the cure for this trouble is to raise the chromium and nickel contents. Heterogeneity of the austenitic solid solution plays a part in this phenomenon, which is simply intercrystalline corrosion of a particular type caused by the intervention of mechanical stresses of internal or external origin. In the case of chromium-bearing carburised ferro-nickels containing more nickel than the 18/8 steels, tempering after quenching may likewise cause the deposition of carbides, but the γ–α transformation in the adjacent metal (which may occur in the 18/8 alloy) is avoided. To obtain a numerical value for the degree of heterogeneity of the austenite solid solution, the author plots temperature-magnetisation curves for the alloys ; the heterogeneity can then be expressed by the difference between the Curie point of the specimen and that of the untempered alloy and by the area between the experimental curve and a hypothetical curve coinciding with it at the starting point. The author presents a study of the influence of factors in the heat treatment on the production of heterogeneity ; the very great accelerating effect of cold-work following the quench and of stress applied during tempering is pointed out. He also gives diagrams showing the influence of the heterogeneity on the general properties of the allcys ; the liability to fissuring corrosion was determined in a hydrochloric acid solution of sodium thiosulphate and was indicated by an increase in the resistivity. Parallelism between all the various curves is apparent ; in particular, the rôle of heterogeneity in the intercrystalline corrosion of the alloys is confirmed ; further, as heterogeneity necessarily precedes precipitation of the carbides, an explanation is provided for the divergence, observed in studies of the phenomena of structural hardening, between the increase of hardness and the precipitation revealed by the microscope or other means.

The Effect of Ferrous Iron in Solutions of Citric Acid of Different Hydrogen-Ion Concentration on the Corrosion of Iron in the Presence of a Limited Supply of Air. J. M. Bryan. (Transactions of the Faraday Society, 1934, vol. 30, Nov., pp. 1059–1062). Experiments were performed in which specimens of mild steel sheet were subjected to the corroding action of a citric acid solution, the H-ion concentration being varied. Ferrous iron was added in some cases and the effect observed ; the corrosion loss and hydrogen evolution were measured, and the results plotted against H-ion concentration. Other curves were also

derived. The curves reveal the type of corrosion (whether oxidation or hydrogen-evolution) which occurs and the action of ferrous iron. The author discusses the results so obtained.

The Corrosion of Steel by Sulphuric Acid. S. Ram. (Journal of the Society of Chemical Industry, 1935, vol. 54, Apr. 19, pp. 107T–109T). Experiments were carried out to determine the effect of acid concentration and the presence of ferrous sulphate on the rate of corrosion of iron and steel in sulphuric acid. Two steels were used, one being very free from impurities, the other of commercial grade. In each case the usual period of induction was observed; hydrogen evolution was slower for the purer material, but the ferrous sulphate appeared to be without effect.

Corrosion of Wrought Iron and Steel. R. Morgan, P. D. Dalsimer, and N. Smith. (Journal of the Franklin Institute, 1935, vol. 219, Feb., pp. 157–165). Details are given of experiments carried out on specimens of wrought iron and steel immersed in corrosive media. The specimens were cut from pipe to give both longitudinal and transverse sections. The potential-time curves were plotted using an $N/10$ calomel cell; an automatic recording apparatus was employed. These experiments were repeated, using annealed specimens and pieces having a coating of mill scale.

Investigations on the Corrosion of Interlocked Sheet Piling in River and Sea Water. C. Holthaus. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Mar., pp. 379–388). In the harbours of Amrum (North Sea), Emden (brackish water) and Lünen (river water), tests were made on interlocked piling walls to determine the degree of corrosion attack and to discover what life might be expected of these walls, which had been built twenty years ago. Sections were cut out from various zones, including under-water areas, and the degree of rusting was estimated. In all three cases, the minimum average loss had occurred where the corrosion was due to air only. The attack was much greater in the region between wind and water and particularly at the air-water contact zone or just below the water-line; deeper down below the surface the attack was less again. Regarding the durability there need be no hesitation as to the use of interlocked piling in river or sea-water; previous estimates of a life of 80 to 120 years would appear to be not excessive.

The author next describes an examination of a protective staging on the island of Sylt, near Westerland; here the effect of corrosion was secondary to the mechanical erosion caused by sand stirred up by the action of the waves; in some places complete penetration of the metal had occurred. In conclusion, the author discusses means of increasing the life of such structures when submitted to erosion; a new profile for the piles has been developed. Laboratory tests to determine the resistance of

various steels to the erosion of sand and water have been instituted ; up till the present the differences between the resistances of the steels tested has been no more than 20 per cent.

The Corrosion Problems of the Naval Architect. W. H. Hatfield. (Institution of Naval Architects, Apr. 12, 1935 : Engineer, 1935, vol. 159, May 3, pp. 472–474). The author describes many of the observations and experiments made by the Corrosion Committee of the Iron and Steel Institute and British Iron and Steel Federation, concerning marine corrosion. Examples are given of cases of abnormal corrosion. The author goes on to discuss the degree of protection afforded by the use of chromium and nickel-chromium in steels, and the results of some experiments on the behaviour of these alloy steels in saline waters.

Corrosion of Steel in Shipbuilding. W. E. J. Lewis. (Journal of the West of Scotland Iron and Steel Institute, 1935, vol. 42, Jan., pp. 61–66). Corrosion appears to have become a more serious trouble in post-war than in pre-war years. In the case of rivets, this may be due to the use of rimming steel (now prohibited by Lloyd's). As far as plates are concerned, the higher temperatures used in rolling and the shorter weathering time seem to be important factors. Descaling by pickling is effective, but expensive ; some other method must be sought. Internal corrosion may be brought about by the presence of electrolytes in a liquid cargo (such as petroleum) ; the attack is most severe at the bottom of the tanks. The bottom of the tank may be cemented, but the remedy is costly.

Ocean Transportation of Petroleum in Bulk. R. F. Hand. (North-East Coast Institution of Engineers and Shipbuilders : Iron and Coal Trades Review, 1935, vol. 130, April 19, p. 657). In this paper the author refers to the problem of the corrosion of oil tankers. In general, the corrosion is caused by the nature of the cargo carried in combination with the use of sea-water ballast, fatigue of material, and, to a somewhat lesser extent, the salt-laden atmosphere and sea-water temperatures in which the tankers operate.

Corrosion Protection in Hot-Water Supply and Heating Systems. E. Naumann. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, May 4, pp. 545–546). A general discussion of the corrosion problem in regard to hot-water systems and central heating plants.

Motor-Electrolytic Current as a Factor in Corrosion. E. Newbery. (The Electrochemical Society, 1935, Preprint 67–3). The brass pipe and driving rod of a deep-well pulsometer pump were found to be severely corroded, and experiments were carried out to ascertain the cause. External conditions were simulated as far as possible. It was discovered that the corrosion could be attributed to motor-electrolytic currents generated by the rapid

motion of an electrolyte (in this case diluted sea-water) over the surface of the rod and the interior of the pipe. The outer surface of the latter, being in contact with undisturbed electrolyte, formed the cathode of the cell, and remained unattacked.

Failures in Steel and Cast Iron Mains and Provisions for their Protection. E. F. Reid. (The Institution of Civil Engineers, 1934, Selected Engineering Papers, No. 154). This paper consists of a review of the causes of failures in water mains, together with the methods adopted for their protection. The failures are classified as (*a*) structural and mechanical, (*b*) physical, (*c*) chemical, (*d*) electrical. The various causes of mechanical breakdown are : Lack of cover ; vibration ; subsidence ; lack of sufficient anchorage ; pressure due to excessive depth ; defective pipes ; and faulty valves. Frost is the principal cause of physical failures, though earthquakes and lightning are occasional factors. The waters dealt with may be classified by the *p*H value, and rendered harmless by the addition of suitable salts, or by de-aeration. Tuberculation sometimes takes place, due to bacterial attack, but is not a cause of corrosion. Where the *p*H value cannot be adjusted it may be necessary to coat the pipes internally with bitumen compounds or spun cement ; or abestos-cement pipes may be used. External corrosion may be explained on the basis of the electro-chemical theory, and suitable protective measures applied. The nature of the corrosive attack depends on the type and concentration of the salts present in the soil. A concrete surround affords good protection, but is expensive ; back-fillings of a sandy description are often effective ; thin coats of paint are usually insufficient, especially in acid or alkaline soils, and it is then necessary to use heavy mastic coatings. Asbestos-cement pipes are attractive since they are non-corrodible. Mains laid near sources of electric supply are sometimes subject to attack due to stray currents and the electrolytic action to which they give rise. Insulated joints, or, alternatively, bonding and subsequent connection to the negative bus-bar, may be adopted. It is better to use return-feeders to convey the current, but this is costly. The author quotes a number of practical examples.

Corrosion and Other Damage to Tube Material in Underground Works. C. Abweser. (Korrosion und Metallschutz, 1935, vol. 11, Mar., pp. 59–64). The author discusses the various corrosion phenomena that may be observed on tube materials (particularly iron and lead) in underground works ; in that connection he deals with bitumen-base coating materials, and shows in what directions it is necessary to improve these substances. Particular attention is paid to the effects of stray electric currents and to protection against them. He concludes with a reference to the dangers due to frost and mechanical action, to which pipe systems are exposed.

Corrosion of Metal Fastenings in Zinc-Chloride-Treated Wood. R. H. Baechler. (Industrial and Engineering Chemistry, 1934, vol. 26, Dec., pp. 1336–1338). Zinc chloride is widely used in America as a preservative for wood. From the results of tests it would appear that the corrosion of wire nails in wood treated with zinc chloride and exposed to moderately humid interior or to outside conditions, is not appreciably greater than the corrosion of nails in untreated wood, provided the treated wood is seasoned before the nails are driven. Nails driven into wet treated wood and exposed to the foregoing conditions corrode rapidly during the drying period.

Accelerated Tests of Nickel and Chromium Plating on Steel. P. W. C. Strausser, A. Brenner, and W. Blum. (Journal of Research of the National Bureau of Standards, 1934, vol. 13, Oct., pp. 519–526). Plated specimens were subjected to accelerated corrosion tests, using a salt spray and intermittent immersion in a salt solution. A 20 per cent. sodium chloride solution at 35° C. was used. The specimens were inspected periodically for rust spots, and a rating was given ; the results are compared with those obtained by atmospheric corrosion tests. It was found that the resistance to corrosion depends largely on freedom from porosity, while this in turn varies with the thickness of the coating. By using a solution containing sodium chloride and potassium ferricyanide, porosity in coatings of nickel on steel is revealed by the appearance of blue spots. Similar tests may be applied to other coatings.

The Durability of Tin and Zinc Coatings under Corrosion Fatigue Stresses. J. Krystof. (Metallwirtschaft, 1935, vol. 14, Apr. 19, pp. 305–307). After touching on previous investigations, the author describes his own tests, in which 9·5 mm. diam. steel bars, coated with tin or with zinc, were submitted to a fatigue test while sprayed with artificial sea-water. Under heavy stressing and low numbers of alternations, the electroplated zinc coating appeared to be superior to the hot-dipped zinc coating, as the latter gave rise to a tendency towards local corrosion. At high numbers of stress reversals this superiority disappeared ; owing to the low fatigue strength of the electroplated zinc, the coating became scored with innumerable fissures, which grew rapidly owing to the action of local elements and to the consequent increased speed of solution. In the hot-dipped zinc coating, unsuitably orientated crystals became damaged by fine cracks, the formation of local elements and chemical changes. The tinned specimens, which broke after a low number of stress alternations, revealed marked rust formation along the fatigue cracks in the tin layer ; this demonstrated the importance of the relative positions of the coating and basis metals in the electro-potential series, for the slightest damage to or porosity in a

coating with a higher potential than the basis metal leads to corrosion-fatigue failure.

The Diffusion of Hydrogen Through Mild Steel Sheet During Acid Corrosion. T. N. Morris. (Journal of the Society of Chemical Industry, 1935, vol. 54, Jan. 18, pp. 7T–13T). The scope of the investigation described was limited, in the main, to the diffusion occurring with (*a*) mild steel sheet in the white annealed condition, (*b*) tinned mild steel sheet, and (*c*) lacquered mild steel sheet. The acid used was a 1 per cent. solution of citric acid, either plain or with the addition of various substances known to affect the speed of the reactions. The general method of carrying out the tests is outlined. It is suggested that the technique employed in measuring the diffusion of hydrogen through steel provides one more approach to a fundamental study of the attack of acids on steel. The results throw light on the action of inhibitors and accelerators of acid corrosion by providing experimental evidence that, although these may not all act in precisely the same way and may not be entirely without effect on the reaction $2H \rightarrow H_2$ and the formation of bubbles of hydrogen, they mainly affect the rate of deposition of atomic hydrogen on the metal.

A coating of tin on the side of the sheet not in contact with acid has been shown to retard the diffusion of hydrogen through steel, but the diffusion was not checked completely, owing, in all probability, to discontinuities in the tin layer. A film of oxide also retarded diffusion, but a coating of lacquer had little effect.

In the presence of air of a humidity of 50 per cent. and over, a film of oxide or hydroxide with interference tints formed on the side of the steel not in contact with acid. This film did not appear unless diffusion of hydrogen was taking place, and provides an example of the special activity of the hydrogen under these conditions.

Corrosion of Tinned Iron Containers. O. Carrasco. (Giornale di Chimica Industriale, 1934, vol. 16, pp. 329–334). The extent of the corrosion varies greatly with the nature of the tinplate, and the presence of appreciable quantities of sulphur increases the rate of corrosion considerably.

CHEMICAL ANALYSIS.

ANALYSIS OF IRON AND STEEL.

The Determination of Alumina in Steel. P. Klinger and H. Fucke. (Technische Mitteilungen Krupp, 1935, vol. 3, Mar., pp. 4–14). (*See* Journ. I. and S.I., 1934, No. II. p. 727).

The Determination of Ferrous and Manganous Oxides in Steel by Means of Mercuric Chloride. E. Maurer, P. Klinger, and H. Fucke. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Mar., pp. 391–398 : Technische Mitteilungen Krupp, 1935, vol. 3, Mar., pp. 15–30). The authors have tested out a method of estimating the ferrous and manganous oxides in steel, in which the metal is decomposed in an aqueous solution of mercuric chloride and the iron and manganese in the residue are estimated. The stability of ferrous and manganous oxide in the mercuric chloride solution was proved and the influence of compounds of iron with carbon, silicon, phosphorus, sulphur, and nitrogen, and of manganese with sulphur was determined. The ferrous oxide in various steels was determined by the new method, and the results were compared with those obtained by other methods for the estimation of oxygen. Tests to decide to what steels the method could be applied showed that it could give unquestionable results only for steels containing less than 0·05 per cent. of phosphorus, sulphur or nitrogen, and less than 0·4 per cent. of chromium. In conclusion, the authors describe a method of recovering the mercuric chloride.

The Iodine Method for the Determination of Oxides in Steel. T. E. Rooney and A. G. Stapleton. (Iron and Steel Institute, May, 1935 ; this Journal, p. 249).

The Determination of Aluminium in Steel. Part I.—The Determination as Phosphate. P. Klinger. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Feb., pp. 337–347). The estimation of aluminium in steel has been submitted to a critical investigation. A method of carrying out the assay has been worked out and tested. Of the usual alloying elements, chromium, titanium and vanadium interfere with the process, but means for avoiding this are given. Contrary to the usual opinion, the research demonstrates that the phosphate precipitation method for aluminium gives very good results, even for complex steels. Finally, a rapid works method for use with simple steels was tested.

The Spectrographic Rapid Determination of Alloy Elements in Special Steels. O. Schliessmann. (Technische Mitteilungen Krupp, 1935, vol. 3, Mar., pp. 31–40). (*See* Journ. I. and S.I., 1934, No. II. p. 728).

Copper Determination by Alpha-Benzoin Oxime in Copper-Molybdenum Alloy Steels. H. A. Kar. (Industrial and Engineering Chemistry, Analytical Edition, 1935, vol. 7, May 15, p. 193). The copper is precipitated with H_2S, ignited, redissolved in HCl, converted to an ammoniacal solution, and in this state precipitated by α-benzoin oxime. The residue is filtered and ignited to copper oxide. The time taken is 1 hr.

A Potentiometric Method of Estimating Molybdenum and Titanium in Steel, Ferro-Alloys, Slags and Ores, in the Presence of Iron and its Accompanying Elements. P. Klinger, E. Stengel and W. Koch. (Technische Mitteilungen Krupp, 1935, vol. 3, Mar., pp. 41–57 : Archiv für das Eisenhüttenwesen, 1935, vol. 8, Apr., pp. 433–443). The authors show that the oxidation of trivalent molybdenum to the pentavalent condition after previous reduction by zinc and chromous chloride in hydrochloric acid solution can well be followed potentiometrically in the presence of large quantities of foreign salts. The commencement and likewise the end-point of the oxidation are indicated by a jump in the potential curve ; thus, molybdenum can be estimated quantitatively, and the method is applicable to steels, ferro-alloys, slags and ores. In the oxidation of trivalent titanium to the quadrivalent state after reduction by zinc and chromous chloride, the potential curve is similar to that for the oxidation of molybdenum ; this reaction can also be followed in the presence of large amounts of foreign salts, and can be applied to the estimation of titanium. The authors show that the potentiometric results are quite as accurate as those obtained gravimetrically, and the former method has the advantage in regard to the time required ; further, separation of other elements is not necessary, and the use of hydrogen sulphide is avoided.

Determination of Molybdenum in Steels. L. Losana and M. Jarach. (Industria Chimica, 1934, vol. 9. pp. 623–625).

Determination of Molybdenum in Steel and Its Separation from Tungsten. W. Werz. (Zeitschrift für analytische Chemie, 1935, vol. 100, pp. 241–257). A critical study has been made of the determination of molybdenum in steel, and of the interference of tungsten. As regards the precipitation of molybdenum sulphide, the author confirms the fact that pressure precipitation with hydrogen sulphide is not necessary. The essential factor for complete precipitation is a very rapid current of the gas ; this will precipitate the metal quantitatively, even from solutions containing phosphoric acid. Copper is the only other member of the hydrogen-sulphide group found in alloy steels ; for its

separation from molybdenum, the mixed sulphides are boiled for a few minutes with 20 ml. of 10 per cent. caustic soda. The filtrate from the copper sulphide is boiled with 5 ml. of ammonium sulphide solution, and the molybdenum sulphide is precipitated by excess of dilute sulphuric acid, collected and ignited to trioxide.

Occurrence and Determination of Nitrogen in Steel. W. W. Stevenson. (Industrial Chemist, 1934, vol. 10, pp. 307–309).

Colorimetric Rapid Method for the Estimation of Silicon in Iron and Steel. H. Pinsl. (Giesserei, 1935, vol. 22, Feb. 15, pp. 78–79). (*See* Journ. I. and S.I., 1934, No. II., p. 727.)

Contribution on the Rapid Determination of Silicon in Iron, Plain and Alloy Steels by Photometry. P. Klinger and W. Koch. (Technische Mitteilungen Krupp, 1935, vol. 3, Mar., pp. 58–61). Recently, Pinsl (Archiv für das Eisenhüttenwesen, 1934–35, vol. 8, p. 97) described a rapid method in which the silicon in iron and steel was determined colorimetrically or photometrically. The present authors report on improvements which they have introduced into the method and on the applicability of the process. They conclude that the method is not generally applicable to all special steels; it is suitable for iron and plain steels and for a few special steels. For steels containing tungsten, titanium, vanadium or more than 2 per cent. of manganese, the method is uncertain. In the presence of aluminium it cannot be applied. Nickel and molybdenum do not affect the results, provided that the phosphate addition (used in the preliminary separation) is correctly adjusted. Too much chromium renders the material insoluble in nitric acid, and in that case also the method cannot be used.

The Estimation of Sulphur in Ferro-Alloys. C. Holthaus. (Archiv für das Eisenhüttenwesen, 1935, vol. 8, Feb., pp. 349–355). The author first gives brief details of four standard methods of estimating sulphur in ferro-alloys (the ether process, the evolution process, the combustion method and the fusion method). He then gives an account of a research to determine the suitability of these methods for a large variety of ferro-alloys, on the basis of which he indicates which method is most suitable for any particular alloy.

Determination of Sulphur in Plain and Alloy Steels. L. Silverman. (Industrial and Engineering Chemistry, Analytical Edition, 1935, vol. 7, May 15, p. 205). A modification of Meineke's method of copper chloride extraction is introduced, in which the usual evaporation with HCl is replaced by evaporation with perchloric acid.

The Determination of Zirconium by means of Phenylarsenious Acid (Determination in Iron, Steel, Ferro-Zirconium, Coating Materials and Zirconia Bricks). P. Klinger. (Technische Mitteilungen Krupp, 1935, vol. 3, Mar., pp. 1–4). (*See* Journ. I. and S.I., 1933, No. II., p. 715.)

The Determination of Trivalent Chromium in Chromic Acid and in Chromium Plating Baths. H. H. Willard and P. Young. (The Electrochemical Society, 1935, Preprint No. 67–7). A new method is described of estimating trivalent chromium in plating baths. It depends on oxidation of the chromium by means of ceric sulphate and titration of the excess with standard sodium nitrite. The end-point is determined potentiometrically. The results obtained show that the method is both rapid and accurate, whilst moderate quantities of impurities commonly present in plating baths (such as Fe, Mn) do not interfere. The percentage of Cr_2O_3 in chromic acid may also be estimated by this method.

Rapid Determination of Nickel and Chlorides in Nickel-Plating Solutions. W. R. Meyer. (Metal Industry (N.Y.), 1934, vol. 32, pp. 306–307).

Modern Spectroscopy. H. Dingle. (Journal of the Royal Society of Arts, 1935, vol. 83, Jan. 25, pp. 234–245; Feb. 1, pp. 258–272; Feb. 8, pp. 283–301). An outline is given of the principles of modern spectroscopy, and the applications of those principles are considered.

Present State of the Spectro-Analytical Investigation of Impurities in Materials. H. Moritz. (Zeitschrift des Vereines deutscher Ingenieure, 1934, vol. 78, Dec. 15, pp. 1453–1456). The author first indicates recent developments in the apparatus used in spectrum analysis; he then discusses qualitative analysis by this means, and deals with the determination of the other elements found in iron. Finally, he deals with quantitative analysis, and gives brief details of the homologous line-pair method, the three-line method of Scheibe and Schnettler, and the method developed by the Zeiss Company.

Spectrum Chemical Analysis, 1860 and 1935. W. Gerlach, E. Riedl and W. Rollwagen. (Metallwirtschaft, 1935, vol. 14, Feb. 15, pp. 125–132). The authors discuss the foundation of spectro-analytical methods, their development during the years, technical utilisation, and the modern application of spectro-analysis to the examination of rocks, ores and alloys.

Spectrophotometric Determination of Manganese in Steel. J. P. Mehlig. (Industrial and Engineering Chemistry, Analytical Edition, 1935, vol. 7, Jan. 15, pp. 27–29). Manganese can be practically completely separated from iron and the other metals usually present in steel by precipitation as hydrated manganese dioxide with excess ammonium persulphate in boiling 1 : 50 sulphuric acid solution. The spectrophotometric method when carefully carried out is capable of giving results for manganese in steel that are correct to within $\pm$ 0·1 per cent. For manganese in solution the precision is about $\pm$ 0·1 mgr. per litre. Although concentrations of manganese below 2 mgr. per litre may be read directly from the curves, it is advisable either to increase the

sample weight or to make the permanganate solution up to a volume less than 1 litre; that will call for the use of the more nearly vertical portion of the curves. The method may be carried out in a comparatively short time and has the advantage over the colorimetric methods of requiring no colour standards. However, it has no advantage over the volumetric bismuthate method; the two methods are to be regarded as alternative procedures.

ANALYSIS OF ORES AND FLUXES.

An Investigation of the Benzoate Method for the Separation of Iron, Aluminium, and Chromium, and Some Suggested Changes for its Application to Qualitative Analysis. L. Lehrman and J. Kramer. (Journal of the American Chemical Society, 1934, vol. 56, Dec., pp. 2648–2649).

Normal-Propylarsonic Acid as a Reagent for the Determination of Zirconium. F. W. Arnold, jun., and G. C. Chandler. (Journal of the American Chemical Society, 1935, vol. 57, Jan., p. 8). *n*-propylarsonic acid is shown to be a satisfactory reagent for the direct determination of zirconium in the presence of a number of elements, including tin, from which a separation has not heretofore been obtained by reagents of this type. Some properties of allylarsonic acid as an analytical reagent are also described.

Selenite-Phosphate Method for Determining Zirconium in Ores. S. G. Simpson and W. C. Schumb. (Industrial and Engineering Chemistry, Analytical Edition, 1935, vol. 7, Jan. 15, p. 36).

ANALYSIS OF FUEL.

Determining the Correct Weight of Sample in Coal Sampling. L. S. Kassel and T. W. Guy. (Industrial and Engineering Chemistry, 1935, vol. 7, Mar. 15, pp. 112–115). The authors have developed a mathematical treatment of the theory of coal sampling for float-and-sink determinations and the results are shown to agree well with practical sampling tests. Methods are suggested for the actual use of the theory to determine sample sizes.

Some Notes on the Sampling and Analysis of Coal. A. G. Bell. (Coke-Oven Managers' Association, Jan. 24, 1935: Gas World, 1935, vol. 102, Feb. 2, Coking Section, pp. 9–11). Routine sampling, ash balance and the determination of volatile matter, ash and carbon dioxide are dealt with.

The Mechanisation of the Drawing of Samples in Coal Washeries. E. Lewien. (Glückauf, 1935, vol. 71, Mar. 23, pp. 279–283). The author first discusses the minimum bulk of sample that should be drawn and the various factors which influence it. He then deals with the separation according to grain-size and density which occurs when coal " flows " or is " poured " as from a chute, and its influence on the representative character of the sample, and describes proposals that have been made for avoiding these sources of error by mechanising the process of sampling.

The Interpretation of a Coal Analysis. A. Dawe and G. Coles. (National Association of Colliery Managers: Iron and Coal Trades Review, 1935, vol. 130, Mar. 22, pp. 497–498; Mar. 29, pp. 536–537). A review of methods adopted by the Fuel Research Board for the sampling and analysis of coal.

Combustion of Sulphur-Bearing Coals. Flue-Gas Compositions and Waste-Gas Losses. J. W. Arbatsky and E. Praetorius. (Zeitschrift des Bayerischen (Dampfkessel-) Revisions-Vereines, 1934, vol. 38, p. 88: Zeitschrift des Vereines deutscher Ingenieure, 1934, vol. 78, Dec. 8, pp. 1438–1439). The erroneous assumption, that in the analysis of waste-gases in the Orsat or other apparatus the sulphurous acid, like steam, is without effect owing to prior absorption in water, is still widespread. The authors' tests, in which the products of the combustion of carbon disulphide with varying amounts of air were analysed in an Orsat apparatus, show that both CO_2 and SO_2 were in fact absorbed in the caustic solution. The error introduced by neglecting the sulphur content of waste-gases decreases with increasing carbon content in the fuel. Thus, in high-grade coals with 70 to 90 per cent. of carbon, a higher sulphur content introduces a smaller error than less sulphur in a lower-grade brown coal. The amount of excess air and the waste-gas temperature also affect the error, which increases as they increase.

Confining Liquids for Gas Analysis. K. A. Kobe and J. S. Williams. (Industrial and Engineering Chemistry, Analytical Edition, 1935, vol. 7, Jan. 15, pp. 37–38). A solution containing 20 per cent. by weight of sodium sulphate and 5 per cent. by volume of sulphuric acid is recommended as the most practical confining liquid for use in technical gas analysis. The addition of acid to sodium sulphate or sodium chloride solutions causes no appreciable increase in the solubility of carbon dioxide, and is necessary to prevent the solution from becoming alkaline at any time.

An Improved Slow-Combustion Pipette for Gas Analysis. D. J. Porter and D. S. Cryder. (Industrial and Engineering Chemistry, Analytical Edition, 1935, vol. 7, May 15, pp. 191–192). The authors describe a slow-combustion pipette in which the combustible mixture is made to flow through a fine platinum

capillary ube, impinging on a small heated platinum spiral placed just in front of the nozzle. The apparatus is quite safe in use.

Determination of Water and Hydrogen Sulphide in Gas Mixtures. F. Fraas and E. P. Partridge. (Industrial and Engineering Chemistry, Analytical Edition, 1935, vol. 7, May 15, pp. 198–199). Normally the analysis of gas mixtures containing water and hydrogen sulphide is attended by difficulties due to condensation of the water and attack of the mercury by the H_2S. A suitable absorption train is described in which anhydrous copper sulphate is used to absorb H_2S, and magnesium perchlorate to remove water vapour.

Determination of Benzol in Gas with the Interferometer. E. König. (Glückauf, 1935, vol. 71, June 8, pp. 543–545). The author first describes the principle and construction of the interferometer, its standardisation and use, and then presents a comparison of the results obtained with this apparatus, by the active charcoal method and by the refrigeration method, showing that they agree reasonably well.

NOTICES OF RECENT BOOKS PRESENTED TO THE LIBRARY.

"*Bibliography of Non-Metallic Inclusions in Iron and Steel.*" Compiled by L. F. McCombs and M. Schrero. (Mining and Metallurgical Investigations under auspices of Carnegie Institute of Technology, and Mining and Metallurgical Advisory Boards, Co-operative Bulletin 70). 8vo, pp. 308. Pittsburgh, Pa., 1935: Mining and Metallurgical Advisory Boards. (Price $4.)

The investigator in the field of ferrous metallurgy is confronted with a tremendous mass of data in almost any line of work which he may undertake, and nowhere is this more true than when it comes to a study of inclusions in steel. This bibliography contains no less than 2,136 references to the literature on the subject, the information being widely scattered, and specific information being often concealed under a general title. The terminology is likewise extremely confused and even to-day there is no generally accepted nomenclature, so that the title of "Non-Metallic Inclusions in Iron and Steel" chosen for this bibliography will probably not find favour with all metallurgists. Every item in the list has been examined and checked, a practice which is not at all general in the compilation of bibliographies, as those who have much occasion to use them know only too well. Where possible, the reference is to the original publication, followed by references to reprints, translations or abstracts found elsewhere. Brief annotations are added in every case, not to serve the function of abstracts, but to help the user of the bibliography to decide whether it is worth while for him to consult the original. The references are arranged in the alphabetical order of the authors' names, no classification having been attempted, but a most excellent index at the end supplies any need there may be for a suitable classification. Research workers concerned with the study of inclusions will find the book to be the most complete bibliography of the whole subject.

"*Bochumer Verein für Bergbau und Gusstahlfabrikation in Bochum.*" Neun Jahrzehnte seiner Geschichte im Rahmen der Wirtschaft des Ruhrbezirks von Walther Däbritz. La. 8vo, pp. 451. Illustrated. Düsseldorf, 1934: Verlag Stahleisen, m.b.H. (Price 12 marks.)

The old-established great steel foundry at Bochum, known universally under the name of the Bochumer Verein, was amalgamated in 1926 with the Vereinigte Stahlwerke (the United Steel Works) of Düsseldorf, but it regained its independence in 1933, when the combination was dissolved, and it resumed its activities under its old name. The original firm out of which the Bochumer Verein grew was founded in 1842. This was the steel foundry of Mayer and Kühne, which began to manufacture crucible steel of the best quality, and, independently of Krupp, achieved a high reputation for its products. It is indeed claimed for Jacob Mayer, the original founder of the enterprise, that he was the first to discover the art of making moulded steel castings. In 1854 the works were taken over and the present company, the Bochumer Verein, was formed. Two other well-known names are

associated with the undertaking, namely, Helmholtz, who was engaged there in the "seventies," and Felix Scharf who was responsible for the great developments of the firm from 1900 to 1910. The present book gives an historical account of the works from the earliest days down to the present time, covering a period of 92 years, and it contains many interesting drawings and illustrations taken from the archives of the firm.

"*The Book of Stainless Steels. Corrosion Resisting and Heat Resisting Chromium Alloys.*" Edited by E. E. Thum. Second Edition. 8vo, pp. xii + 787. Illustrated. Cleveland, Ohio, 1935: The American Society for Metals.

The first edition of this book appeared in 1933, and the fact that a second and considerably enlarged edition has now become necessary speaks much for the importance and interest of the subject. The work may be regarded as an example of the advantage to be derived from the co-operation between the steelmaker and user, since the production and consumption of the heat- and corrosion-resisting alloys of iron, the number of which is astonishing, now play so important a part in industry, that to give a full account of them is a task almost beyond the ability of any single man. Accordingly, the present compilation, which is fairly complete in all details, represents the joint effort of 75 men, each an expert in some branch of industry and technology. It is too much to expect that there should not be some differences of opinion among such a group of men, not only as to the limitations and adaptability of certain alloys, but even about the primary metallurgy and fundamental structure of the principal alloys. In such cases the editor has attempted to call the attention of the authors of the respective chapters to the points at issue, and the more important instances where opinions are in conflict are noted by editorial footnotes, with the object of cautioning the reader to investigate such points with care. To meet the difficulties which arise in the nomenclature and classification of the high-chromium heat-resistant and corrosion-resistant steels the editor has grouped all these under the term "Stainless Steels." Trade names have been generally avoided in the text, but a complete list of American trade names will be found at the end of the book. Alternative nomenclature is based on the microstructure; if the alloy is substantially ferrite it is called an iron; if it is martensitic, or hardenable by quenching, it is called a steel; and if it remains austenitic after heat treatment it is called an austenitic steel or austenitic alloy. Precise definitions will be found in the book. The whole forms a complete work on American practice in the manufacture and uses of corrosion-resisting steels.

Boys, Sir C. V. "*The Natural Logarithm.*" Sm. 4to, pp. 31. Illustrated. London, 1935: Wightman & Co., Ltd. (Price 2s.)

This little book explains the relation between the natural logarithm and the common logarithm, natural logarithms being another term for the Naperian logarithms. These are often called hyperbolic logarithms, for the reason that they are equal to the areas under the hyperbolic arcs representing the ratios. They are now most commonly known as logarithms to the base e, e being the symbol universally adopted to denote the quantity of which the natural logarithm is 1. The book is not intended to replace the usual exponential treatment, but those who have to teach elementary mathematics might find it useful for the enlightenment of their pupils who may demand a simplified explanation of the real meaning of the systems of logarithms.

"*British Chemicals and Their Manufacturers.*" "The Official Directory of the Association of British Chemical Manufacturers (Incorporated)." 8vo, pp. 459. London, 1935: The Association. (Issued gratis to genuine purchasers of chemicals).

This directory was last issued in 1933, and it has now been revised and brought fully up-to-date. The intention is that an up-to-date edition shall appear every second year, so that the next may be expected to appear in 1937. The object of the Association is to encourage and facilitate business relations between manufacturing and chemical firms, and purchasers of chemicals all over the world. The book is not only the official directory of the Association, but it also forms a complete buyer's guide, in which the products of the chemical industry are arranged in alphabetical order, their names being printed in five languages besides English, and the names of the firms or individuals supplying the product appear opposite each item. A list of proprietary goods and trade names follows the general list, and at the end is printed an index, which is repeated in each of the six languages employed in the book, namely, English, French, Spanish, Portuguese, Italian, and German. The directory should be of considerable value to commercial attachés, consular officers and trade commissioners all over the world.

BULLENS, D. K. "*Steel and Its Heat Treatment.*" Third Edition, Rewritten and Reset. Third Printing, including Chapter on Nitriding. 8vo, pp. xiii + 580. Illustrated. New York, 1935: John Wiley & Sons, Inc.; London: Chapman and Hall, Ltd. (Price 25s.)

Since the publication of the third edition in 1927, so many advances have been made in metallurgical science and in the art of heat-treating steel, that a new printing of the third edition has become necessary for the incorporation of new matter and comment on present-day practice. The work is divided into three sections: The metallurgical part, dealing with the general principles and practice of heat-treatment processes; the engineering part, in which the distinctive attributes of the various alloy steels are discussed; and the production part, relating to the principles and practice of industrial heating as applied to heat-treating processes. The chapter on "Testing" has been re-written so as to take account of recent studies of repeated impact and miscellaneous stresses. The importance of spheroidising is recognised by the incorporation of a separate chapter on that subject, and the chapter on hardening has been expanded to illustrate the importance of the rate of cooling and the effect of mass and surface. New chapters on the metallurgy of special alloy steels have also been added, and an important feature is the well illustrated account of electric equipment for heat treatment. The third printing of the third edition afforded an opportunity of including a special chapter on the nitriding of steel, contributed by V. C. Homerberg, this being—in the author's opinion—the most important development in the heat treatment of steel from the commercial and practical point of view since 1927. The book has long been recognised as a standard treatise on works practice in the heat treatment of steel, and the new printing of the third edition will be welcome alike to managers and operators of heat-treatment plants.

CAMPBELL, H. L. "*The Working, Heat Treating, and Welding of Steel. Supplemented with a Series of Laboratory Assignments.*" 8vo, pp. ix + 185. Illustrated. New York, 1935: John Wiley & Sons, Inc.; London: Chapman and Hall, Ltd. (Price 11s. 6d.)

The purpose of this work is to present in concise form the principles and the practice of the manufacture, heat treatment, and welding of steel. A useful series of laboratory instructions is appended to the text as a guide to students. The book is an elementary treatise on steel, planned to assist in the introductory study of certain prescribed phases of the metallurgy of steel, and all unnecessary terms and dimensions are excluded which rightly belong to more advanced studies in these topics.

DAVIES, H. J. "*Precision Workshop Methods.*" 8vo, pp. viii + 306. Illustrated. London, 1935: Edward Arnold & Co. (Price 20s.)

The growth of interchangeable manufacture, which has helped so largely to promote the mass-production of machines of all kinds, has only been made possible by the provision of tools, jigs and fixtures of extreme accuracy. Much ingenuity has been expended in devising methods of the necessary precision and in this book an attempt is made to bring together in a convenient form some of the essential ideas upon which precise work depends. A great deal of the matter is based on the notes used for a course in machine shop work for engineering students. The workshops have been treated as a laboratory in which the work of the lectures was demonstrated and thoroughly tested, and in this way the students were able to obtain a very sound knowledge of the principles underlying machine work. The methods dealt with have not only been well tried in practice but have been tested under conditions which may be even more searching, and, in the author's opinion, they may be used in full confidence. Chapters on machinability and limit systems have been included. At first sight these may appear to be outside the scope of the subject, but some consideration will show that these questions constitute very important factors in precise work.

GEISSEL, A. "*Die Schablonenformerei in Sand und Lehm.*" (Die Betriebspraxis der Eisen-, Stahl- und Metallgiesserei. Eine Sammlung von Einzelabhandlungen aus dem Gebiete praktischer Giessereitechnik. Herausgegeben von H. Hermanns. Heft 21.) 8vo, pp. viii + 137. Illustrated. Halle (Saale), 1935: Verlag von Wilhelm Knapp. (Price 8.80 marks.)

In this book the author describes the technology and practice of strickle-board moulding. For moulding in loam it is the oldest method known, and an account of it is to be found in Biringuccio's "Pirotechnia," printed in 1550. For moulding in sand, however, the use of the strickle-board was not introduced until about 60 years ago, and being mainly a foundry operation not much has been written on the subject. Some useful notes have now been compiled by the author on the preparation and consistency of the moulding material, and a variety of strickle-boards and templates are illustrated for the instruction of iron moulders in the art and practice of this method of making moulds.

GREAVES, R. H. "*Chromium Steels.*" (Department of Scientific and Industrial Research.) 8vo, pp. vi + 321. Illustrated. London, 1935: H.M. Stationery Office. (Price 7s. 6d.)

The first pages of this work give an account of the discovery and early history of the use of chromium and of the first experimental chromium steels made by Stodart and Faraday. Specimens of these, with others, were lately recovered and described by Sir Robert Hadfield. In view of the

existence of well-known authoritative books on stainless iron and steel and the numerous and very important quaternary alloys containing chromium with other elements, no reference is made to these classes of steels, and the subject-matter is confined to the consideration of plain chromium steels only, the information concerning which has remained scattered. Such steels are universally used for balls and ball-bearings and the low-chromium steels also have useful properties for structural and general engineering purposes. They are largely employed in the automobile industry, likewise for special castings, gauges, dies, magnets, rails and exhaust valves for internal combustion engines. The book takes the form of a critical summary of the literature of chromium steels and contains besides a description of some hitherto unpublished work carried out at Woolwich on the influence of such quantities of silicon and manganese as may be found in plain chromium steels, and on the effect of mass in heat treatment. Evidence as to the constitution of the binary and ternary alloys of iron, carbon and chromium is presented and illustrated by the necessary diagrams, and mechanical and physical properties are discussed in the light of numerical values, the information being supplemented by an ample bibliography of the existing literature. Those interested in analytical chemistry will find in an appendix a full critical survey of the methods of chemical analysis suitable for chromium steels, and the volume should thus prove of interest both to the engineer and to metallurgists generally.

HABERT, F. "*Wärmetechnische Tafeln.*" Unterlagen für die Rechnungen des Wärmeingenieurs in Schaubildern und Zahlentafeln. Herausgegeben mit Unterstützung der Wärmestelle Düsseldorf des Vereins deutscher Eisenhüttenleute. Anlage: "Wo finde ich?" Schrifttumsverzeichnis für feuerungstechnische Berechnungen, zusammengestellt von H. Schwiedessen. La. 8vo. Düsseldorf, 1935: Verlag Stahleisen, m.b.H.; Berlin: Julius Springer. (Price 14.50 marks.)

This book might more accurately have been entitled "Heat Calculations made easy," since it consists of a carefully chosen collection of diagrams and tables, containing the most important physical and chemical data which heat-economy engineers, gas engineers, physicists and chemists may require for their studies. The whole is combined in a single handy volume for daily use, arranged in loose leaf form which permits of adding any new material or substituting a new table or diagram for an old one that may have fallen out of date. Appended to the work is an index showing the original source of the principal monographs and text-books on the general subjects of industrial heating and fuel.

HARRIS, H. "*Metallic Arc Welding.*" 8vo, pp. viii + 199. Illustrated. London, 1935: Edward Arnold & Co. (Price 16s.)

Metallic arc welding as an industrial operation has been practised for many years, and it is somewhat surprising perhaps to find that the developments in arc-welding technique are not so widely known as they might be. Since some of these developments are of outstanding importance, in considering new applications of the art, an attempt to summarise the present knowledge of the subject is the chief aim of this new book. The greater part of the work is concerned with the welding of mild steel. Certain alloy steels and alloys are discussed, but in this connection it is apparent that a great deal of experimental work remains to be done before a complete and satisfactory solution of all the problems can be reached. Other alloy steels

and alloys which have been welded are omitted from consideration because no satisfactory data could be obtained, or because the methods employed have resulted in welds which cannot be described as first-class. No attempt is made to discuss in detail the effect of electrode coating compositions on the resultant weld, as the task is made somewhat difficult by the reticence shown by electrode manufacturers in disclosing the compositions and behaviours of their electrodes, and although ordinary chemical analysis reveals the effective composition, knowledge so gained is not for public discussion. The book is, however, a useful contribution to the knowledge of a subject which still tends to be surrounded by the mystery of a secret process.

HEILIGENSTAEDT, W. "*Wärmetechnische Rechnungen für Bau und Betrieb von Öfen.*" Herausgegeben von der Wärmestelle Düsseldorf des Vereins deutscher Eisenhüttenleute. 8vo, pp. 186. Düsseldorf, 1935: Verlag Stahleisen, m.b.H. (Price 11.50 marks.)

The active research on the theory and practice of furnace construction and furnace operation which has been carried on during the last few years at the "Wärmestelle" of the Verein deutscher Eisenhüttenleute has made possible the formulation of certain definite principles and rules for the calculation of heat balances and the data dependent thereon for the correct design of boilers and metallurgical furnaces. In view of the fact that construction engineers are more interested in the principles governing design and in the results which can be obtained by their application, the aim of the author has been to produce a book in which the main part of the abstruse mathematical calculations for the derivation of the rules is omitted, and the work is restricted to the presentation of only those formulæ and rules which are necessary to obtain the best results. By this means the arithmetical calculations have been simplified and clarified so as to leave only what is essential for the speedy working out of plans without involving the expenditure of time in tracing out the subject from first principles. All heat-economy engineers will welcome the book on that account.

HERTY, C. H., JUN., AND ASSOCIATES. "*The Physical Chemistry of Steel Making.*" (Mining and Metallurgical Investigations under auspices of Carnegie Institute of Technology, and Mining and Metallurgical Advisory Boards). 8vo. Illustrated. Pittsburgh, Pa., 1934: Mining and Metallurgical Advisory Boards. (Price $3.)

In 1926 the Metallurgical Advisory Board undertook a five-year programme for the study of the physical chemistry of steel-making, including, in particular, the study of non-metallic inclusions, their nature, properties, and methods of determination and elimination. The results of this work have been published from time to time in a series of bulletins and in the technical press. The original programme was completed in 1931 and the work was continued for another period of three years. The results of the investigations carried out under the new programme are given in a number of bulletins which are now published in the present volume. These are as follows: Bulletin 64, "The Effect of Deoxidation on the Rate of Ferrite Formation in Plain Carbon Steels," by C. H. Herty, jun., M. W. Lightner, and D. L. McBride; Bulletin 65, "The Effect of Deoxidation on Grain Size and Grain Growth in Plain Carbon Steels," by C. H. Herty, jun., D. L. McBride, and S. O. Hough; Bulletin 66, "The Effect of Deoxidation

on the Ageing of Mild Steels," by C. H. Herty, jun., and B. N. Daniloff: Bulletin 67, "Effect of Deoxidation on the Impact Strength of Carbon Steels at Low Temperatures," by C. H. Herty, jun., and D. L. McBride; Bulletin 68, "The Control of Iron Oxide in the Basic Open-Hearth Process," by C. H. Herty, jun., C. F. Christopher, H. Freeman, and J. F. Sanderson; Bulletin 69, "The Deoxidation of Steel," by C. H. Herty, jun. Abstracts of the contents of each Bulletin appear in Section II. of this Journal.

HOPKIN AND WILLIAMS, LTD. "*Organic Reagents for Metals*," by the Staff of the Research Laboratory of Hopkin & Williams, Ltd. Second edition. 8vo, pp. 107. London, 1934: Hopkin and Williams, Ltd. (Price 1s. 3d.)

The second edition of this little book has been enlarged by the inclusion in it of an additional number of organic reagents for use in inorganic analysis. There is no doubt that a wide field has now been opened up in this direction. Two great advances may be noted, the first of which is that these methods place in the hands of the chemist reagents which are extremely sensitive and in many cases definitely specific, leading to a great saving of both material and time. These two properties are also essentials in the use of "spot" tests, of which a varied assortment is described. Another aspect is the use of these reagents in the colorimetic determinations of traces of metals, since many of the organic reagents enable one to effect separations when necessary by the use of immiscible solvents. A valuable feature of the phamphlet is that an up-to-date bibliography is given for each reagent. The book is commended not only to practising analysts but also to teachers, so that students may become acquainted with these modern methods.

HOUDREMONT, E. "*Einführung in die Sonderstahlkunde.*" 8vo, pp. xii + 566. Illustrated. Berlin, 1935: Verlag von Julius Springer. (Price 52.50 marks.)

The author, in his capacity as manager of Messrs. Krupp's Steelworks, has had exceptional opportunities for gaining experience in the production of special steels, including practically every known type of alloy steel in commercial use at the present day, and his book will, therefore, rank as one of the most authoritative on the subject of the manufacture, properties, and uses of the numerous classes of material included under the general term "special steels." Generally speaking, these fall into three classes, though in most cases the same conditions characterise each class in a greater or less degree. The author's classification consists of (1) special steels as influenced by composition; (2) special steels as influenced by the method of production; and (3) special steels which owe their qualities to heat treatment. Pure iron may reasonably be included in the second class, since it can only be produced by some special method and is not obtainable by the ordinary processes of manufacture. The author confines himself mainly to a discussion of the steels forming the first of these three classes, and the work falls into two principal sections. The first one deals exhaustively with iron-carbon alloys of varying carbon content, beginning with the elucidation of the iron-carbon system and the practical application of the iron-carbon diagram. The second section discusses the principal alloy steels in commercial use to-day. In compiling the book the practical details of the subject have been strictly adhered to and these are presented in a manner which will be clearly intelligible to technically-trained men whether engaged in the manufacture of special steels or in the daily use of such material.

LEA, F. M., and C. H. DESCH. "*The Chemistry of Cement and Concrete.*" 8vo, pp. xii + 429. Illustrated. London, 1935: Edward Arnold & Co. (Price 25s.)

This work gives a general survey of the chemistry of cement and concrete and is not intended to be a manual of instruction in the operation of a cement plant nor to furnish descriptions of the numerous types of machinery employed in the industry, these subjects being fully treated of in other text-books. But the chemistry of the changes which the raw materials undergo in the course of cement production is fully dealt with, and an account is given of the effect of change in composition and other factors on the properties of the finished products. The testing of cement is discussed only in general outline, the reader's attention being directed primarily to an examination of the value and significance of the various tests. Two outstanding events in the history of cement manufacture in the last 25 years are the introduction of aluminous cement and the production of rapid hardening Portland cement. Aluminous cement is characterised by its rapid hardening properties and its resistance to sulphate attack, but since the only suitable material commercially available for its manufacture is bauxite, which is expensive, the finished product is too costly to permit of a very widespread use, and the discovery of a cheaper raw material is a problem still unsolved. In the case of Portland cement the changes in manufacture which have been made in recent years have resulted in a very marked increase in the rate of hardening. Indeed, this increase has been carried to such a degree as to lead to a neglect of other important properties of cement, the consequences of which are now becoming apparent. The lesson that may be drawn from the recent history of Portland cement production appears to be that when manufacture outruns both research and experience the progress obtained in one direction is liable to be offset or nullified by adverse changes simultaneously introduced. Unless progress is slow, experience alone cannot suffice, and it is on research both in the production and properties of cements and concretes that the cement industry must rely. It should be added that a full account of the chemistry of the production of cement from blast-furnace slag is given. The book is intended for the chemist, and also for the engineer and architect, who have to deal with cement, and whereas the earlier chapters may probably be considered to be the private preserve of the chemist, engineers and architects will certainly find in the later chapters information, otherwise difficult of access, on many problems of importance to them in their work.

LESSNIKOFF, M. "*Sir Henry Bessemer. A Biography in Russian.*" Sm. 8vo, pp. 255. Illustrated. Moscow, 1934.

This is probably the first biographical notice of Sir Henry Bessemer to appear in the Russian language, and the author is to be congratulated on the completeness of the work, especially in view of the fact that much of the necessary material which had to be consulted was not to be found in the technical libraries in Russia.

Some points in the history of the introduction of the Bessemer process of steelmaking are put forward from a somewhat different point of view from that generally accepted. The volume, of which over 50,000 copies have been printed, is offered as a contribution to the memory of the great inventor.

MARSH, J. S. "*Principles of Phase Diagrams.*" With a Foreword by John Johnston. (Alloys of Iron Research. Monograph Series).

8vo, pp. xv + 193. Illustrated. New York and London, 1935: McGraw-Hill Book Co., Inc.

Courses of instruction and text books which include the "phase rule" have usually taken the qualitative point of view, especially in the case of courses of metallurgy. One result of such treatment is that the iron-carbon diagram, for instance, is often something to be memorised by the student rather than something to serve as a key to the first principles of the phase theory. Metallurgical literature frequently now contains a large number of phase diagrams, the ternary diagrams being often of so complicated a character as to be undecipherable without the provision of a key, and the only satisfactory plan for imparting a clear understanding of such diagrams appears to be the giving of a good grounding in the principles underlying the theory. The final purpose being an adequate development of these principles, it was ultimately decided that, without entering too far into the field of advanced theory, it would suffice for the student to spend as much time on theory as would enable him to work out special cases and then to provide him with a usable interpretation of the diagrams given. In addition, some space has been given to such topics as the theory of solutions, since it seemed desirable to indicate the relation of that to the basic theory from which the phase diagram is derived. Likewise an attempt has been made to maintain an orderly nomenclature. As an example, the word "singulary" is used to denote a system of one component in place of unary or monary, as in conjunction with the words, binary, ternary, and so on, the terminology of the different phases becomes more consistent. The author has achieved a difficult task in stating, in brief compass, the main principles and the arguments involved in the derivation and practical use of the theories treated of in this book.

"*Med Hammare och Fackla. VI.—Arsbok Utgiven av Sancte Örjens Gille.*" (Year-Book published by the Guild of St. George.) 8vo, pp. 185. Illustrated. Stockholm, 1935.

This forms the sixth issue of the Year-Book of the Guild of St. George, a publication devoted to historical research in the craft of metalworking, with biographical notes of the celebrated craftsmen of the early Swedish industries.

MELLER, K. "*Taschenbuch für die Lichtbogenschweissung.*" 8vo, pp. viii + 189. Illustrated. Leipzig, 1935: Verlag von S. Hirzel. (Price 5 marks.)

The author's earlier text-book on Electric Arc Welding met with so successful a reception, that he was urged by his many friends engaged in the actual practice of welding, to issue a pocket book on arc welding for the benefit of foremen, workmen and apprentices specialising in the welding industry generally. The book deals mainly with the welding of steels, but it also includes chapters on the cold- and hot-welding of cast iron and the welding of non-ferrous metals, and it finishes up with a description of methods of testing welds. The author begins with an account of the plant and accessories used for welding with direct current and with alternating current, whether generated on the spot or taken from the grid. Considerable space is devoted to a discussion of the different types of electrodes, their manipulation and the qualities of the welds produced by them, besides much other useful practical information on such matters as shrinkage, distortion, and the mechanical and thermal treatment of welds.

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"*Mitteilungen aus den Forschungsanstalten des Gutehoffnungsh ütte-Konzerns.*" Herausgegeben von der Konzernstelle der Gutehoffnungshütte, Aktienverein für Bergbau und Hüttenbetrieb. Oberhausen (Rhld). Band 3. Heft 7, Feb., 1935. pp. 171–198. Illustrated. Berlin: V.-D.-I. Verlag, G.m.b.H. (Price 3.15 marks.)

The present number of this publication contains three monographs. The first, by K. Schlaefke, of the Augsburg-Nuremberg Engineering Company, discusses the modifications in the principles of the design of high-speed internal-combustion engines, as necessitated by the introduction of the Diesel engine for the propulsion of motor vehicles. In the second, J. Uebing, of the Gutehoffnungshütte, deals with the design of railway cross-overs with sharp bends. The third article, by H. Kopp, of the Esslingen Engineering Works, is on the subject of the most suitable quality of cast metal for the cylinders of air-cooled motors, with special reference to a copper addition. The heat conductivity of the metal is thereby increased, and there is also an increase in the Brinell hardness. On the other hand, it was noted that the resistance to wear was diminished by adding copper to the mixture.

"*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns.*" Band 3, Heft 9. June, 1935. La. 8vo, pp. 233–256. Illustrated. Berlin, 1935: V.-D.-I. Verlag, G.m.b.H. (Price 3.80 marks.)

The contents of this number consist of three articles, the first of which, by H. Hammerschmid, C. F. Linström and G. Scheibe, describes an investigation of the spark and arc spectra of pure iron as an aid to the qualitative emission spectral analysis of iron alloys. The second is a study by P. Cicin of the distribution of stresses in the flat ends of built-up steel cylinders of large diameter; and the third is a discussion by O. Goffin of the influence of abnormal composition of the granular matter used as additions in the manufacture of concrete on the strength of the product.

"*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns.*" Band 3, Heft 10. July, 1935. La. 8vo, pp. 257–284. Illustrated. Berlin, 1935: V.-D.-I. Verlag, G.m.b.H. (Price 3.15 marks.)

Number ten of the same volume contains two monographs, the first of which is a contribution to the theory of the buckling of thin plates by K. Sattler, and the second, by O. Holtschmidt, describes the MAN apparatus for the fatigue testing of materials.

"*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf.*" Herausgegeben von F. Körber. Abhandlung 244 bis 270. Band XVI. La. 8vo, pp. 239. Illustrated. Düsseldorf, 1934: Verlag Stahleisen m.b.H. (Price 27 marks.)

The publications of the Kaiser-Wilhelm-Institut für Eisenforschung are welcomed by both metallurgists and engineers. The present volume reports the results of recent investigations carried out in the Research Laboratories

of the Institute, under the Directorship of Dr. Körber. It contains twenty-one papers dealing chiefly with ferrous metallurgy. Notes and references to these papers will be found in Section II. of this and other volumes of the *Journal of the Iron and Steel Institute*. In view of the important nature of the research work reported, copies of this work should find a place in all metallurgical laboratories and research institutions. The contents of the volume are as follows: The Heat of Formation of the Iron Carbide Fe_3C, by G. Naeser; Coarse-Grained Recrystallisation of High-Carbon Steel, by A. Pomp; Localised Formation of Martensite in Steel Wire, by A. Pomp; The Röntgenographic Measurement of Elastic Stresses, by H. Möller and J. Barbers; The Influence of Friction and of the Cross-Sectional Dimensions on the Flow of Material in Rolling, by E. Siebel and E. Osenberg; Investigations on the Hot-Drawing of Weldless Steel Tubes, by A. Pomp and U. Schylla; Influence of Treatment during Melting with Ferrous-Oxide-Rich and Acid Low-Protoxide Slags on the Crystallisation and Mechanical Properties of Grey Cast Iron, by P. Bardenheuer and A. Reinhardt; The Basic Principles of the Desulphurisation of Pig Iron and Steel, by P. Bardenheuer and W. Geller; On the High-Frequency Induction Furnace. IX.—Further Contribution on the Metallurgy of the Crucible Steel Process, by P. Bardenheuer and W. Bottenberg; On the High-Frequency Induction Furnace. X.—The Production of Tool Steel in the Coreless Induction Furnace, by P. Bardenheuer and W. Bottenberg; The Resistance to Deformation during the Rolling of Steel in Box Passes, by E. Siebel and W. Lueg; Influence of the Carbon Content and Heat Treatment on the Drawability of Steel Wire, by A. Pomp; Influence of the Carbon Content and Patenting Conditions on the Strength Properties of Drawn Steel Wires, by A. Pomp; The Hydrogen Brittleness of Steel in Relation to the Quantity of Hydrogen Absorbed, by P. Bardenheuer and H. Ploum; The Penetration of Brazing Solder into Iron as a Result of Hydrogen Absorption during Pickling, by P. Bardenheuer and H. Ploum; The Question of the Creep Limit of Steel above 500°, by A. Pomp and H. Herzog; The Influence of the Arrangement of the Specimen on the Results of Measurements on Epstein Test-Pieces, by F. Wever and H. Lange; Influence of the Structure on the Creep Strength of Steel, by W. Enders; The Magnetic Properties of Natural and Artificial Iron-Oxygen Compounds. Part I.—Magnetic Measurements on Specimens in Powder Form, by W. Luyken and L. Kraeber; Influence of the Shape of the Test-Piece, the Type of Grip, and the Rate of Testing and the Testing Machine on the Position of the Upper and Lower Yield Points of Steel, by F. Körber and A. Pomp; Investigations on the Course of the Metallurgical Reactions in the Acid Open-Hearth Process, by P. Bardenheuer and G. Thanheiser; The Form of Combination of Carbon in Hardened and Tempered Steel, by F. Wever and G. Naeser; The Specific Heat of Iron Carbide Fe_3C, by G. Naeser; The Thermal Decomposition of Iron Carbide Fe_3C, by G. Naeser; The Deformation Conditions in Wire Drawing, by E. Siebel; Stresses and Flow of Material in Tube Drawing, by E. Siebel and E. Weber; The Dependence of the Commencement of Flow on the Stress Distribution and the Material, by E. Siebel and H. F. Vieregge.

Society of Chemical Industry. "*Reports of the Progress of Applied Chemistry.*" Vol. xix. 1934. 8vo, pp. 838. London: The Society. (Price: Members, 7s. 6d.; Non-members, 12s. 6d.)

As usual, this year-book reports all the important developments in the field of chemical science and industry which have become known in 1934. The advances made in the study of fuel gas and the derivatives of the distillation of coal, mineral oils, refractories, iron and steel and non-ferrous

metals, and the electro-chemical and electro-metallurgical industries form the subject of principal interest to those engaged in the iron and steel industry. The progress report on iron and steel is compiled by Dr. J. C. Hudson, Investigator to the Corrosion Committee of the Iron and Steel Institute and the British Iron and Steel Federation. This covers 44 pages, and gives an account of the progress achieved in research work throughout the year and in productive developments in the whole field of the iron and steel industry. The Second Report of the Corrosion Committee was published by the Iron and Steel Institute during the year. The year-book continues to maintain its usefulness as a source of reference for everything falling within any of the branches of the chemical industry.

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